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# OBSERVATIONS ON THE PARASITES OF *CYDIA POMONELLA* L. IN SOUTHERN FRANCE

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## INTRODUCTION

The codling moth, *Cydia pomonella* L., in Canada is an insect pest of major importance, particularly in the warmer parts of the country. Even though extensive and costly spraying programs are adopted, these do not seem to check the ravages of the pest, which threatens to make apple-growing unprofitable in large areas of Ontario. Hence it was decided to investigate the possibilities of the biological control of the codling moth in Canada by means of parasites imported from Europe, with the result that the present work was undertaken (Boyce (2) ).

In 1928 and 1929 attempts had been made to obtain European parasites of the codling moth for introduction into New Zealand and South Africa, with a view to the biological control of the pest. Collections of hibernating larvae were made in France by Kozlovsky (Rosenberg (6) ) in the autumn and winter of 1928 and 1929. The material was kept for emergence, and hosts and parasites reared out. Some of the parasites were bred in the laboratory, and shipments of one species, *Ascogaster quadridentatus* Wesm., were made to South Africa and New Zealand. The present work is, in many respects, a continuation and extension of Kozlovsky's and Rosenberg's work, and many references to, and comparisons with, the latter's paper will be made.

### *Site of Investigations*

Kozlovsky made the greater part of his collections in Northwest France, though smaller collections were made eleswhere. In these districts apple-growing is an important industry, but infestation by the codling moth is not excessive, and parasitism was found to be very low (1.37% to 25.75%). Hence a great deal of host material had to be collected in order to obtain few parasites. It was, therefore, preferable to find a locality where parasitism was higher, even though the total number of hosts available might be less.

It was decided that the south of France would probably be a suitable locality for the investigations, although this is not an important apple-growing district. Here, in the Departments of Var and Alpes Maritimes, there are mountains which give, with change of altitude, highly varied climatic conditions. On the coast and in the lower parts of the river valleys the climate is subtropical, the summers are hot and dry, and the winters mild and wet. Higher up the mountains the climate becomes cooler, until

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at St. Martin-Vésubie (3,000 ft.), the highest locality investigated, the climate is sub-alpine. This great range of climatic conditions occurs in a comparatively small area.

With the varying conditions in this district it was hoped that a thorough investigation of the biology of the parasites of *Cydia pomonella* might be made, and that their distribution might be correlated with differences in climatic conditions. Such knowledge would be important when considering the introduction of parasite species for the control of *Cydia* in Canada, since ability to withstand adverse climatic conditions is a necessary characteristic of a parasite that is to be introduced. Hence the investigation was carried on chiefly in the Department of Var in the south of France, between Marseilles and the Italian frontier, though collections were also made near Rouen in Normandy for comparison with those made in the south of France.

*Nature of Countryside*

The coastal strip around Le Lavandou (Var) where laboratory headquarters were set up, is a fertile, and intensively cultivated region. The hinterland consists of cultivated valleys, and hills covered with xerophytic scrub, small pine trees, cork oaks, and *Quercus ilex* bushes. There is little succulent vegetation during the summer, since all that occurs in the spring is completely parched by July. In most places the farmers must irrigate many of their crops in the summer. The chief products are grapes, peaches, almonds, olives and figs. The farms are usually small, and much vegetable growing is done. Over most of the area there are few large orchards; the apple, pear, and quince trees are scattered, several to each small holding. This is a disadvantage in that large collections of *Cydia* material cannot be made from one place, but this is compensated for by the fact that these fruit crops are considered practically valueless, and are not given very effective insecticidal treatment, with the consequence that most of the fruit is attacked by *Cydia*.

There are one or two small areas where apples and pears are extensively grown, notably at Solliès Pont (Var) and the Vésubie valley (Alpes Maritimes). In the former locality the trees are systematically treated with arsenical sprays, etc., and *Cydia* infestations are, to a large extent, kept in check. In the Vésubie valley the change of climate with increasing altitude prevents serious *Cydia* outbreaks. Here, at St. Martin Vésubie, this sub-alpine climate is apparently too severe for *Cydia*, since no infested apples were found, though apples were plentiful. The climate here is hot in the day time during the short summer, cold at night, and very cold in the winter, when several feet of snow occur. From St. Martin Vésubie to the coastal strip there is a gradual transition to the sub-tropical climate. At Roquebillière (2,000 ft.) and La Lantosque (1,400 ft.) *Cydia* larvae were found, and samples taken; but it was only very much lower down, at Colomars and Nice, in the broad valley almost at sea level, that *Cydia* became common. Hence the distribution of *Cydia* itself in the region is considerably limited by climatic conditions, caused by differences in altitude.

During the summer months of 1939, samples of apples were taken from many localities. The apples were dissected to find young *Cydia* larvae, which in turn were dissected to determine percentages of parasitism, and

the parasite species present in these young stages of the host. Numbers of infested apples were also kept in order to rear adult parasites from the *Cydia* larvae.

Also during the summer a large number of fruit trees were banded with 6-inch wide corrugated cardboard bands to obtain hibernating *Cydia* material. Several hundred trees were also banded in Northwestern France near Rouen, where there are many large orchards. However, owing to the more temperate climate, *Cydia* infestations are low; about 15% of the fruit was attacked this summer, compared with 80 to 100% in the south of France. In many orchards careful insecticidal treatment is carried out, and *Cydia* has been eliminated as a serious pest. On the way back to Le Lavandou a number of walnut trees were banded near Grenoble (Isère).

During the latter half of August and September parasites were reared from the samples of maggoty fruit collected, and many hibernating larvae of *Cydia* and parasites were obtained, both from banded trees and by scutinizing the bark of unbanded trees.

Hibernating material thus collected was kept over winter and allowed to emerge in the following spring (1940). The life histories of the emerging parasites were investigated, but the work was brought to an abrupt close with the collapse of France in June 1940, when all material and the majority of the notes on the work had to be abandoned at Bordeaux. Because of this, many exact figures relevant to various aspects of the work have been lost, and allowance must be made for the comparative vagueness of some of the statements concerning the length of life history of parasite species, percentages of parasitism, etc., in those cases where the exact figures are unavailable.

## DISSECTION OF YOUNG LARVAE

In order to investigate the distribution of parasites in the young larval stages of *Cydia*, samples of attacked apples were taken from many localities. The apples were carefully cut up and the *Cydia* larvae removed. These were then dissected, and the parasites contained in them noted. These were:—

*Ascogaster quadridentatus*, Wesm. This occurred as first stage larvae, never more than 1 in a host.

*Pristomerus vulnerator* Panz. Unhatched eggs and young first stage larvae were found. There were sometimes 2 in a host, and this species was found in hosts already containing an *Ascogaster* larva.

*Perilampus tristis* Mayr. Planidia of this species were found in unparasitised *Cydia* larvae, and also in association with *Ascogaster* and *pristomerus* larvae. As many as 8 were found in a single host larva.

The number of host larvae dissected and the parasites found are given in Table 1.

Of the hosts parasitised by *Perilampus*, 4 contained no other parasite. Since *Perilampus* larvae perish if alone in a primary host larva these 4 cannot be included in the number of hosts considered parasitised. Hence the number of hosts parasitised effectively is 112, not 116 as appears from the table; the total percentage parasitism is thus 37.5, not 38.8. Had

TABLE 1.—DISSECTIONS OF YOUNG LARVAE FOUND IN ATTACKED FRUIT

| Locality | — | No. dissected | Unparasitised | *Ascogaster* | *Pristomerus* | *Perilampus* |
|---|---|---|---|---|---|---|
| 6. Le Luc (Var) | 14.vi. 39 | 46 | 30 | 18 | — | — |
| 7. Fréjus (Var) | 19.vi. 39 | 2 | 1 | — | — | 1 |
| 8. Fréjus (Var) | 19.vi. 39 | 23 | 10 | 12 | — | 4 |
| 8. Fréjus (Var) | 19.vi. 39 | 25 | 11 | 13 | — | 2 |
| 9. Le Muy (Var) | 19.vi. 39 | 11 | 10 | — | — | — |
| 11. Le Muy (Var) | 19.vi. 39 | 27 | 20 | 7 | — | — |
| 12. Le Muy (Var) | 19.vi. 39 | 20 | 12 | 6 | 2 | — |
| 12. Le Muy (Var) | 19.vi. 39 | 23 | 15 | 8 | — | — |
| 13. La Farlede (Var) | 23.vi. 39 | 44 | 27 | 15 | 3 | — |
| 14. Le Muy (Var) | 24.vi. 39 | 6 | 3 | 3 | 1 | — |
| 15. Nice (A.M.) | 28.vi. 39 | 17 | 9 | 4 | 3 | 2 |
| 16. Colomars (A.M.) | 28.vi. 39 | 9 | 4 | 2 | 3 | 2 |
| 17. La Lantosque (A.M.) | 28.vi. 39 | 9 | 5 | 4 | 1 | — |
| 20. La Lantosque (A.M.) | 30.vi. 39 | 18 | 12 | 5 | 2 | — |
| 22. Le Lavandou (Var) | 3.vii. 39 | 7 | 5 | — | 2 | — |
| 23. Ste. Maxime (Var) | 6.vii. 39 | 12 | 9 | 1 | 2 | — |
| Total | | 299 | 183 | 99 | 19 | 11 |
| % Parasitism | | — | 61.2 | 33.1 | 6.4 | 3.7 |

the apples been left on the tree, the percentage would probably have been higher. The parasitism by *Ascogaster*, a species parasitising the host eggs, would not have increased, nor would that of *Perilampus*, whose planidia presumably enter the host larva before it burrows into the fruit. However, the host larvae would have been exposed to further attacks by *Pristomerus*, and the amount of parasitism by this species would have been greater.

In order to determine the stage of larva attacked by the three parasite species, records were kept of the head capsule size of each host dissected. These records show that all three species are present in the first stage *Cydia* larvae.

## FRUIT ATTACKED

*Cydia pomonella* has been recorded from many different fruits: apple, pear, quince, peach, chestnut, walnut, etc., and it was thought possible that the parasite complex associated with hosts on different fruits might vary. The various species of fruit trees might have varying degrees of attraction for the adult parasites, or the availability of hosts to ovipositing parasites might differ.

In the early part of the summer apples were found to be the only fruit attacked by *Cydia* to any extent. A few pears were infested, but no larvae were found in quinces. Later, however, pears were more heavily attacked, although still less so than apples. In the autumn quinces suffered heavily, and nearly every fruit contained several larvae. The following figures show the number of larvae collected from banded quince trees compared with the number of fruit on each tree.

LOCALITY 37.—LA FAVIÈRE (VAR). BANDED 31.viii.39.

BANDS AND TREES EXAMINED 22.IX.39 and 21.x.39

| — | No. of fruit | Larvae |
|---|---|---|
| Tree 1 | 60 | 109 |
| 2 | 34 | 52 |
| 3 | 15 | 62 |
| 4 | 44 | 91 |
| | 153 | 314 |

Average—2.05 larvae per fruit.

This figure is no doubt too low, since all the larvae would not make their cocoons on the "host" tree; and even all those that did so would not be found.

Walnut trees were banded at Grenoble in a farm where *Cydia* larvae were found attacking the nuts. These bands, examined at the end of November, contained large numbers of hibernating larvae.

Almonds, plums, chestnuts, and peaches were also banded, but no *Cydia* larvae were obtained.

No difference was seen in the parasite complexes associated with different fruit except in two cases. Both specimens of *Ephialtes rugicollis* Desv. that were reared came from quince trees. The second case was shown by the material from the walnut trees mentioned above. From this material there emerged a larger proportion of *Cryptus sexannulatus* Grav. than was found in other collections, *Trichomma enecator* Rossi was also more common in this material.

## PARASITES REARED FROM LARVAE IN FRUIT

Maggotty fruit was collected as above, but kept in large wooden boxes with gauze tops. The boxes were examined daily, and any fully fed larvae that had come out of the fruit were placed separately in glass tubes where there formed their cocoons. The emergents were then noted.

Parasites reared were:—

*Ascogaster quadridentatus* Wesm.
*Pristomerus vulnerator* Panz.
*Trichomma enecator* Rossi.

Hyperparasite:—

*Perilampus tristis*, Mayr (parasite of *Ascogaster* and *Pristomerus*).

The figures in Table 2 give the parasites emerging from larvae obtained in these collections.

TABLE 2.—EMERGENTS FROM *Cydia* MATERIAL COLLECTED FROM ATTACKED FRUIT

| Locality | Date | Total larvae | Hibernating | *Cydia* | *Ascogaster* | *Pristomerus* | *Trichomma* | *Perilampus* |
|---|---|---|---|---|---|---|---|---|
| 6. Le Luc (Var) | 14.vi. 39 | 27 | 8 | 13 | 6 | — | — | — |
| 8. Fréjus (Var) | 24.vi. 39 | 49 | 12 | 10 | 21 | — | — | 6 |
| | 11.vii. 39 | 260 | 112 | 96 | 24 | 7 | — | 21 |
| 12. Le Muy (Var) | 24.vi. 39 | 18 | 1 | 15 | 2 | — | — | — |
| | 19.vi. 39 | 9 | 5 | 4 | — | — | — | — |
| | 9.vii. 39 | 96 | 49 | 41 | 4 | — | — | 2 |
| | 9.vii. 39 | 80 | 22 | 48 | 4 | 2 | 1 | 3 |
| | 21.vii. 39 | 35 | 23 | 12 | — | — | — | — |
| 15. Nice (A.M.) | 27.vii. 39 | 48 | 43 | 1 | 1 | 2 | — | 1 |
| 16. Colomars (A.M.) | 27.vii. 39 | 78 | 66 | 4 | 2 | 2 | 2 | 2 |
| 22. Le Lavandou (Var) | 3.vii. 39 | 12 | 1 | 9 | — | 2 | — | — |
| Total | | 712 | 342 | 253 | 64 | 15 | 3 | 35 |
| % Total | | — | 48 | 35.6 | 9.0 | 2.1 | 0.4 | 4.9 |
| % Emergents | | — | — | 68.4 | 17.3 | 4.1 | 0.8 | 9.5 |

Thus the total parasitism was 31.6%. Here, as in the dissections, the percentage of *Pristomerus* and also that of *Trichomma* is probably slightly less than that which would have occurred had the apples been left on the trees, exposed to further attacks by these two species. The individual species reared will be discussed below.

## FIELD EXPERIMENTS

During the summer two experiments were carried out to investigate the following two points.

1. Does the severity of attack by *Cydia*, or the percentage of parasitism, differ at different points on a tree, or are both host and parasite oviposition uniformly distributed? If large differences in this direction occurred, spraying with insecticides might be profitably regulated, so that heavily attacked parts of the tree received most treatment, while those where parasitism was high were untreated. In this way a given amount of insecticide would be used to the greatest advantage; and parasites, which otherwise would have been killed, would be allowed to emerge.

2. Does the variety of apple affect the amount of parasitism or percentage of larvae hibernating? Whether the variety affected the severity of the attack by *Cydia* was not investigated, but results from rearing experiments suggested that the percentage of larvae of the summer generations of *Cydia* that went into hibernation varied with the variety of apple tree.

In the case of the variation of parasitism in different parts of the tree only a single tree was investigated. The fruit was collected into 8 separate lots, from the 4 upper and 4 lower quadrants, the tree being "quartered" at the 4 points of the compass. The attack and emergents from each lot was noted. The southwest part of the tree was more heavily attacked by *Cydia* than the rest, and the *Cydia* larvae in the southeast lower part of the tree were more heavily parasitised than the remainder. Such an

experiment on a single tree is inconclusive evidence, but it is possible that more extensive investigation might indicate some differences in this direction, caused perhaps by such factors as the increased sunlight on the southern side of the tree.

From the experiments on two different varieties of apples, insufficient parasites were reared to see if there was a significant difference in parasitism between the two. There was, however, considerable difference (27.5% and 53.3%) between the numbers of larvae going into diapause rather than emerging (in midsummer) suggesting that the quality of larval food influences the tendency to go into diapause.

## BANDING AND HIBERNATING MATERIAL

In order to collect a quantity of fully grown *Cydia* larvae and to investigate the parasites which attack the larvae within their cocoons, use was made of the familiar method of banding trees with corrugated cardboard. The bands used were about 6 inches in width and were placed as high as possible on the tree trunks, below the first branching. About 700 trees were banded; these were mostly apples, but there were also a number of pears, quinces, and walnuts, and a few plums, almonds and chestnuts. These bands were placed on the trees at varying times until the end of August, and were removed during September, October and November. At the same time as the bands were removed these and other trees were searched for hibernating larvae. The crevices in the trunks were carefully examined and the dead bark stripped off with a penknife.

With smooth barked trees such as young apples and quinces, the proportion of larvae which formed their cocoons in the cardboard bands was considerable; but when the bark was much fissured, as with old apple trees and pear trees, very few larvae were found in the bands, the majority having formed cocoons in the bark itself, showing the necessity of scraping rough barked trees prior to banding.

During this collecting, numbers of parasite cocoons (within *Cydia* cocoons) and insects that are possibly predaceous on hibernating *Cydia* larvae, were also found. These were kept and are discussed below.

The greater part of the material collected in this way remains as hibernating larvae until the following spring. However, a certain number of parasites emerged. These were:—

| | |
|---|---|
| BRACONIDAE | *Ascogaster quadridentatus*, Wesm. |
| ICHNEUMONIDAE | *Pristomerus vulnerator* Panz. |
| | *Trichomma enecator* Rossi |
| | *Ephialtes caudatus* Ratz. |
| | *Cryptus sexannulatus* Grav. |
| CHALCIDIDAE | *Dibrachys cavus* Walk. |
| | *Dibrachys affinis* Masi |
| | *Melittobia acasta* Walk. |

Secondary parasites reared were:—

| | |
|---|---|
| ICHNEUMONIDAE | *Hemiteles*, 1.—From *Cryptus sexannulatus.* |
| | *Hemiteles*, 2.—From *Ephialtes* sp. |

CHALCIDIDAE *Dibrachys cavus* Walk.—From *Cryptus*, *Ascogaster*, and *Pristomerus*.
*Perilampus tristis* Mayr.—From *Ascogaster* and *Pristomerus*.

The hibernating material consisted of about 6,000 *Cydia* larvae and was obtained in two ways:

(*a*) Individuals which went into hibernation from the collections of apples made in the early summer for rearing experiments.

(*b*) From tree trunks and "banded" trees. In addition to this, 150 *Ephialtes* cocoons were collected, about 80 *Cryptus*, and a number of fully grown larvae of *Dibrachys* sp. Several unidentified parasite cocoons were also found. *Ascogaster* and *Pristomerus* were found overwintering as cocoons as well as in young larval stages within hibernating *Cydia* larvae.

As soon as the *Cydia* larvae were collected, they were placed with strips of corrugated cardboard, 1 inch wide and 5 corrugations broad, in which they formed their cocoons. These formed conveniently handled units.

A number of larvae collected were divided into two size groups, since some of them are very much smaller than others. These small larvae have been stated to be parasitised by *Ascogaster*, and it was hoped to see the difference in degree of parasitism between the groups when adults emerged.

All hibernating material was placed in an outhouse on a stone floor, and in February it was examined and placed in glass tubes or in cages suitable for emergence. As stated above much of the material had been separated into two parts, according to the size of the *Cydia* larva, and this distinction was still retained. The majority of the material was "forced" to provide earlier emergence, but some was kept under natural conditions in order to determine the normal times of emergence of the various species. These two categories will be dealt with separately. In both, percentage emergence varied with the conditions under which the hibernating larvae had been kept throughout the winter, and artificial hastening of emergence did not alter this. The best emergence was about 80%, when the larvae, spun up in corrugated strips, had been placed in metal gauze tins within cardboard containers and kept on a stone floor in an unheated outhouse.

*Forcing*

As has already been stated, it was decided, after successful trials, to force out the larger part of the hibernating material so that breeding experiments could be commenced. The material was removed from the boxes in which it had been kept over the winter and was placed in cages or jars kept in constant temperature boxes at 25° C. Each day emergents were removed and recorded. The sequence in which the parasites emerged was the same as that given below for unheated material, and emergence commenced at the beginning of March, about 6 weeks earlier than under natural conditions.

Table 4, drawn up from the few figures available, gives an idea of the percentages of parasitism, and the difference between the "large" and "small" hibernating larvae in this respect. The material was taken from quince trees growing in the hot coastal regions.

With the "small" *Cydia* larvae there were also a number of larvae of *Anarsia lineatella*, and some of the *Ascogaster* and *Pristomerus* may have emerged from this host. The scarcity of *Cydia* in the emergents does not indicate that only few *Cydia* larvae were present, but merely that the majority of these "small" larvae were parasitised. This was seen more clearly in other material. From this table it can clearly be seen that larvae parasitised by *Ascogaster* remain comparatively small before going into hibernation, and that only a very small percentage of these small larvae produce *Cydia* adults. The death rate of the "small" compared with the "large" is very high even though the two groups were kept under similar conditions. It is also evident that the *Cydia* larvae parasitised by *Pristomerus* tend to reach the normal size before hibernation occurs, although the "small" section contains 8.4% of this species in the emergents.

TABLE 4.—EMERGENTS FROM HIBERNATING MATERIAL

| Locality | Size | No. of larvae | No. emerging | *Cydia* | *Anarsia* | *Ascogaster* | *Pristomerus* | *Perilampus* | *Parasitism* |
|---|---|---|---|---|---|---|---|---|---|
| 1. Le Lavandou | Small larvae | 254 | 53 | 1 | 3 | 36 | 7 | 6 | — |
| | | | 20.9* | 1.9 | 3.7 | 67.9 | 13.2 | 11.4 | 92.5 |
| 2. Le May | Small larvae | 100 | 21 | — | 11 | 9 | 1 | — | — |
| | | — | 21.0 | — | 52.4 | 42.9 | 4.7 | — | 47.6 |
| 3. Le May | Small larvae | 103 | 63 | 1 | — | 48 | 5 | 9 | — |
| | | — | 61.3 | 1.6 | — | 76.2 | 8.0 | 14.3 | 98.4 |
| 4. Ste. Maxime | Small larvae | 180 | 78 | — | 54 | 19 | 5 | — | — |
| | | — | 43.3 | — | 69.2 | 24.4 | 6.4 | — | 30.8 |
| Total | | 637 | 215 | 2 | 68 | 112 | 18 | 15 | — |
| | | — | 33.7 | 0.9 | 31.6 | 52.1 | 8.4 | 7.0 | 67.5 |
| 5. Le Lavandou | Large larvae | 70 | 39 | 35 | — | — | 4 | — | — |
| | | — | 55.7 | 89.7 | — | — | 10.3 | — | 10.3 |
| 6. Le Lavandou | Large larvae | 227 | 169 | 109 | — | — | 48 | 12 | — |
| | | | 74.4 | 64.5 | — | — | 28.4 | 7.1 | 35.5 |
| 7. Le Lavandou | Large larvae | 575 | 474 | 402 | — | — | 62 | 10 | — |
| | | — | 82.4 | 84.8 | — | — | 13.1 | 2.1 | 15.2 |
| 8. Le Muy | Large larvae | 43 | 32 | 31 | — | — | 1 | — | — |
| | | — | 74.4 | 97.0 | — | — | 3.0 | — | 3.0 |
| Total | | 915 | 714 | 577 | — | — | 115 | 22 | — |
| | | — | 78.4 | 80.8 | — | — | 16.1 | 3.1 | 19.2 |

* The second line in each case indicates percentage.

*Natural Conditions*

In order to obtain the normal times of emergence of both *Cydia* and its parasites under the conditions prevailing in the south of France, about 1,000 cocoons of the host and parasites were placed out of doors in cages contained in a large wooden box, closed and placed in the sun. A duplicate box was placed next to this, which contained a hygrothermograph for recording temperature and humidity. That this gave almost normal emergence times was confirmed by the observations in the field.

*Hemiteles* spp. emerged first, very much earlier than the rest. The remaining species of parasites, with the exceptions of *Ascogaster* and *Perilampus*, emerged well before *Cydia*. *Ascogaster* began to emerge somewhat after the host, and *Perilampus* was the last to emerge. This can be seen from Figure 1, giving dates of emergence (*Ascogaster* and *Perilampus* only approximate).

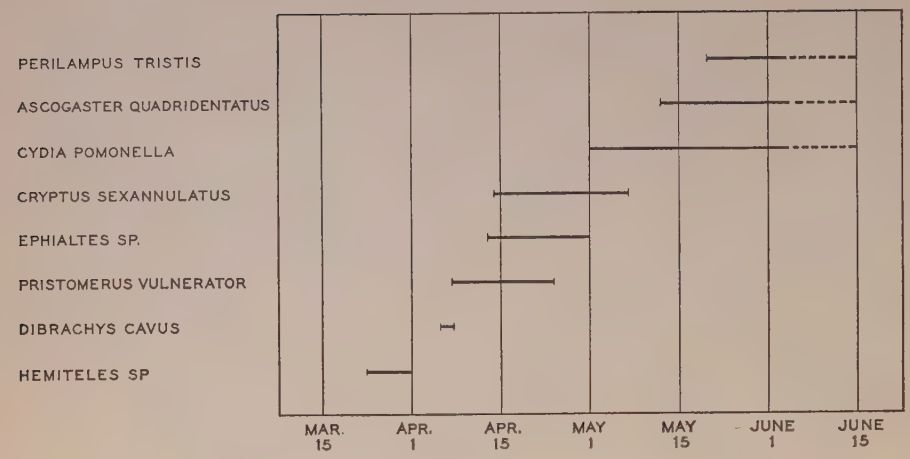


FIGURE 1.

TABLE 5.—ECTO-PARASITISM OF HIBERNATING *Cydia* LARVAE

| Locality | Date | No. of *Cydia* larvae | *Ephialtes* cocoons | *Cryptus* cocoons | *Dibrachys* | *Paralysed* |
|---|---|---|---|---|---|---|
| 11 | 4.xi. 39 | 150 | 29 | 5 | 2 | 5 |
| 12 | 4.xi. 39 | 350 | 5 | — | 3 | — |
| 15 | 13.xi. 39 | 101 | — | 3 | — | 1 |
| 16 | 13.xi. 39 | 20 | — | 1 | — | 1 |
| 20 | 13.xi. 39 | 73 | 3 | 5 | — | 3 |
| 23 | 26.xi. 39 | 460 | 7 | 4 | 11 | 8 |
| 24 | 20. x. 39 | 243 | 21 | 2 | — | — |
| 25 | 19.ix. 39 | 77 | 5 | — | — | — |
| | 18. x. 39 | 36 | 2 | — | — | — |
| 27 | 10.ix. 39 | 541 | — | 1 | — | — |
| | 23.xi. 39 | 156 | — | 18 | — | 2 |
| 35 | 13.xi. 39 | 245 | 1 | 8 | — | 3 |
| 36 | 13.xi. 39 | 59 | 5 | 1 | — | 1 |
| 37 | 16.ix. 39 | 147 | 3 | — | — | 1 |
| | 18. x. 39 | 51 | 1 | — | — | — |
| | 22. x. 39 | 227 | 14 | 3 | 1 | — |
| 38 | 3.ix. 39 | 160 | — | — | — | — |
| 39 | 15. x. 39 | 60 | — | — | — | 2 |
| 40 | 17. x. 39 | 23 | 1 | — | — | — |
| 41 | 18. x. 39 | 11 | 1 | — | — | 2 |
| 42 | 18. x. 39 | 55 | — | — | — | 2 |
| 43 | 19. x. 39 | 243 | 2 | 3 | — | 1 |
| 44 | 22.xi. 39 | 104 | 1 | — | — | 4 |
| 45 | 23. x. 39 | 9 | 3 | — | — | 1 |
| 46 | 24. x. 39 | 148 | 4 | 5 | — | 9 |
| 47 | 25. x. 39 | 137 | 7 | — | — | — |
| | | 15 | 1 | — | — | — |
| | | 25 | 1 | — | — | — |
| 48 | 25. x. 39 | 64 | 1 | 1 | — | — |
| 49 | 4.xi. 39 | 11 | — | — | — | — |
| | | 3990 | 118 2.8% | 60 1.4% | 17 0.4% | 46 1.1% |

Total number attacked by parasites: 241 = 5.7%.

*Ectoparasites in Hibernating Material*

An indication of the percentage parasitism by ecto-parasites of the hibernating *Cydia* larvae in their cocoons is given in Table 5. This shows the number of parasite cocoons and larvae collected, at the same time as the collections of hibernating *Cydia* larvae were made. Owing to the fact that parasities may be on the wing and ovipositing in the autumn after the collections were made, and that, as is seen in the diagram, they emerge (or start ovipositing) before *Cydia* emerges in the spring; the figures in Table 5 are certainly lower than the real percentage parasitism achieved by these species.

No significant difference is seen between the percentage parasitism of *Cydia* larvae taken from apples, pears, or quinces. From those taken from bands on walnut trees, the same parasite species were obtained but the percentage of *Trichomma* and *Cryptus* was much higher. Also no difference was noted due to varying locality, or to climatic variation in the mountains. Hibernating larvae from North France were so few as to give no results.

*List of Parasites Emerging from Hibernating Material*

PRIMARY PARASITES

ICHNEUMONIDAE:

| | |
|---|---|
| *Pristomerus vulnerator* Panz. | Endoparasitic within *Cydia* larva. |
| *Trichomma enecator* Rossi | Endoparasitic within *Cydia* larva. |
| *Ephialtes caudatus* Ratz. | Ectoparasitic on *Cydia* larva in cocoon. |
| *E. crassiseta* Thoms. | Ectoparasitic on *Cydia* larva in cocoon. |
| *E. ruficollis* Desv. | Ectoparasitic on *Cydia* larva in cocoon. |
| *E. cydiae* Perk. | Ectoparasitic on *Cydia* larva in cocoon. |
| *Cryptus sexannulatus* Grav. | Ectoparasitic on *Cydia* larva in cocoon. |

BRACONIDAE:

| | |
|---|---|
| *Ascogaster quadridentatus* Wesm. | Endoparasitic on *Cydia* larva. |
| *Meteorus(?)chrysophthalmus* Nees | Endoparasitic on *Cydia* larva. |

CHALCIDIDAE:

| | |
|---|---|
| *Dibrachys affinis* Masi | Endoparasitic in *Cydia* pupae. |
| *D. cavus* Walk. | Ectoparasitic on *Cydia* larvae. |

TACHINIDAE:

| | |
|---|---|
| *Arrhinomyia tragica* Mg. | Endoparasitic in *Cydia* larva. |

SECONDARY PARASITES

ICHNEUMONIDAE:

| | |
|---|---|
| *Hemiteles* spp. | Parasitic on *Ephialtes*, *Cryptus*, and *Pristomerus* cocoons. |

CHALCIDIDAE:

| | |
|---|---|
| *Perilampus tristis* Mayr. | Parasitic on *Pristomerus*, *Cryptus* and *Ascogaster*. |
| *Dibrachys cavus* Walk. | Parasitic on *Pristomerus*, *Ephialtes*, *Cryptus* and *Ascogaster* cocoons. |

The list contains only species which are definitely known to have emerged from *Cydia pomonella* L. Besides the above there were 2 further unidentified species of Ichneumonidae and 2 Chalcididae, single specimens of which emerged from the *Cydia* material.

With the emergents from hibernating material experiments on the length of life of the adult parasites and the life histories of the species were started, and will be dealt with under each species separately.

## PREDATORS AND DISEASE

In the "bands" and under the bark of trees examined for hibernating *Cydia* larvae, numbers of possible *Cydia* predators were taken; these included: *Tenebrioides mauritanicus* L. (TEMNOCHILIDAE); *Dolichosoma lineare* Rossi (MELYRIDAE); *Cantharis* (? *rustica* Fall.) (CANTHARIDAE); *Malachius* (? *bipustulatus* L.) (MELYRIDAE); *Mecynstarsus* (? *serricornis* Panz.) (ANTHICIDAE).

All of these are Coleoptera. Raphidiid larvae, Geophilids, and the mite *Pediculoides ventricosus*, Newp., are also possible predators.

These predators were all tested in the laboratory with *Cydia* cocoons, but in no case were the experiments successful, and the value of insect predators in the control of *Cydia* in the south of France would appear to be negligible.

In many places the "bands" were attacked by birds, the larvae being removed from their cocoons through holes in the cardboard. Lizards have been found under the "bands," and no doubt they destroy a number of larvae descending the tree trunk to form their cocoons.

Many larvae in the cocoons were found attacked by fungus and polyhedral disease, which must decrease the numbers of hibernating larvae considerably in some seasons.

## NOTES ON PARASITES REARED

### HOST

*Cydia pomonella* L.

From forced material the host species began to emerge in the middle of March, from material under natural conditions on 1st May, and was seen in the field a few days later. For breeding experiments with some of the species young larvae were required, and from the middle of March onwards *Cydia* breeding cages were set up under conditions generally supposed to be favourable to the species, 25° to 30° C., and high humidity. Many types of containers were tried, but it was only after some time that a reasonable supply of eggs was obtained, in glass jars kept in the dark at 30° C. No experiments were done on the life history of *Cydia*, the main point of interest being the time of emergence—from 1st May onwards, and the number of generations annually. The second generation was found (in 1939) to emerge from the beginning of July onwards, and individuals which may belong to a partial third generation emerged in September.

## Primary Parasites

*Pristomerus vulnerator* Panz. (*Ichneumonidae, Ophioninae*)

A full host list is given by Rosenberg (6) who makes the suggestion, also indicated here, that the species also parasitises *Anarsia lineatella* Zell. *Pristomerus* apparently occurs throughout Europe, and is found also in Japan.

This species was present in material from all localities investigated, and occurred to the extent of just under 40% in one collection of larvae made from quince trees in the Var. The average percentage was about 10 to 20. *Pristomerus* began to emerge on 7th April and continued to do so until the 24th of this month; the sexes were about equal (about 200 individuals), and the males emerged somewhat before the females. As *Pristomerus* parasitises very young *Cydia* larvae, there would thus be a period of about a month between the earliest emergence of the parasite and the presence of larvae suitable for parasitism. Eggs were found in dissected hosts in the middle of June and adults emerged:—

| July | | | | | | | | | August | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | | | | | | | | | | | | | | |

| August | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | | |
| 1 | | | | | | | | | 1 | 1 | 2 | 1 | | |

| August | | | | | | September | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 21 | 22 | 23 | 24 | | | 12 | | | | | | | |
| 1 | 1 | 1 | | 1 | | | 1 | | | | | | | |

A female was also seen on 30th September ovipositing. Thus there appear to be two generations during the year with a possible partial third in the late autumn.

On emergence in the early spring adults were placed in breeding cages to determine the length of life. They were supplied with honey-water and raisins.

There were three different set-ups:—

1. Adults from material placed at 25° C. to hasten emergence—in small cage.
2. Adults from material emerging under natural conditions:

a. In small cage;

b. In large cage (1 cubic metre).

Between 1 and 2a there was little difference in length of life. There was, however, a great difference in coloration, those from heated material were lightly coloured, with a predominance of red markings and little black coloration; those emerging under natural conditions were, on the other hand, very darkly marked, had little red coloration, and had a greenish sheen.

There was also a striking difference in longevity between adults kept in small cages and those in the large one. Those in the latter cage were much shorter lived than the others; this perhaps was due to their greater opportunity for flying, and hence greater consumption of energy. In all cases males were slightly shorter-lived than females.

In no case was mating observed. However, for breeding experiments females were removed from a cage where about 50 individuals of each sex had been together for some time. These females were placed 5 at a time with 50 young *Cydia* larvae in suitable cages. These cages were 40 cm. in length, 20 cm. wide, and 12 cm. high. The floor and back were made of wood, the two sides of very fine iron-wire gauze, and the top was of glass, let into the wooden framework of the cage, and which could easily be lifted out by turning the fasteners which held it in place. The front was of wood, hinged at the base to act as a door, and in the centre of this was bored a large hole fitted with a cork through which insects could be introduced or removed.

Fitting into these cages, but leaving sufficient room for a jar of honey-water and some raisins, were pieces of wood 2.5 cm. thick, which had 50 holes, 1.5 cm. deep bored in the upper side. Into these holes glass tubes fitted tightly. For oviposition experiments these tubes were prepared as follows.

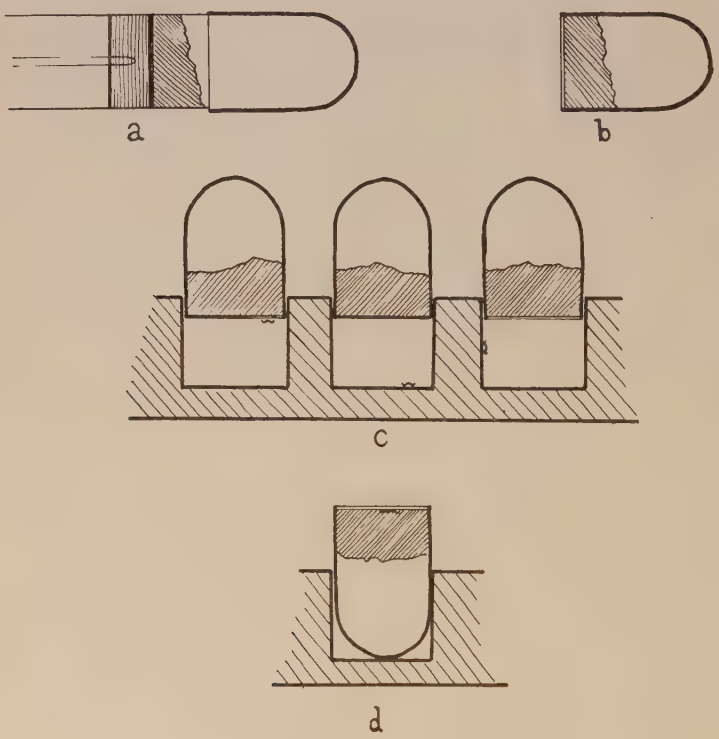


FIGURE 2. Diagrams showing *Cydia* larvae in apple plugs used for *Pristomerus* propagation:—

(a) Cork-borer containing a plug of apple, piston pushing the apple into a glass tube.

(b) Glass tube with apple plug inserted, skin of apple flush with edges of tube and fitting tightly.

(c) Tubes prepared as (b) inverted over holes of the same diameter in wooden block. Single *Cydia* larvae which have just hatched have been confined in these spaces, when they bore into the apple plugs.

(d) After 24 hours tube is inverted in hole, now with *Cydia* larvae just below skin, and ready for parasitisation experiments.

By means of a cork-borer and well-fitting plunger pieces of apple of the same diameter as the glass tubes were inserted into the mouths of the latter so that the apple skin was flush with the edge of the glass (see Figure 2). Freshly emerged *Cydia* larvae were then placed with a brush onto the apple skin, one to each tube, and the tube inverted in one of the holes in the wooden tray (see diagrams). The *Cydia* larva could wander in the air space and eventually bored into the apple plug. After being left for a day to enable the larvae to bore into the apple, the tubes were inverted and placed in the holes with the apple skin exposed (as in Figure 2).

Trays of tubes thus prepared were placed in the cages with the *Pristomerus* females, which showed great interest in the apple plugs and immediately commenced exploring the apple surface with their antennae. Great interest was shown when the antennae reached the holes by which the *Cydia* larvae had bored into the apple, and when they were over frass or other traces of the larvae. When some trace of a host larva was found the female excitedly thrust the ovipositor into the apple or larval tunnel, sometimes inserting the whole abdomen into the latter in an attempt to reach the larva.

In the first trials females were left with smaller trays of larvae for 24 hours or more, after which the larvae were removed from the apple plugs and dissected. In one of these 10 male and 10 female *Pristomerus* were left for two days with 40 prepared apple plugs and then these were examined. Thirty-four larvae were found, the other 6 having presumably wandered off the plugs. These were dissected and contained:—

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. of parasite eggs | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 24 | 27 |
| No. of *Cydia* larvae | 19 | 6 | 1 | 3 | – | 2 | 1 | 1 | 1 |

Thus 84 eggs were laid and 15 out of 34 hosts parasitised.

Unfortunately these are the only exact figures available, but this shows that about 3 eggs were laid per female per diem. In similar experiments superparasitism was always great, and the egg distribution was such that fewer hosts were parasitised than would have been expected from a random distribution of eggs. This was caused by the fact, as seen above, that individual larvae sometimes receive a very large number of eggs. The two larvae which received 24 and 27 eggs in the experiment above were completely choked with parasite eggs, and were moribund. This superparasitism was due to the differing availability of the *Cydia* larvae. Some tunnelled deeply into the apple plug and were completely immune from attack by the parasites; others, having only tunnelled shallowly, were soon heavily parasitised and stung to immobility.

To avoid this the apple plugs were then made thinner (.5 cm.) so that larvae could not become immune by burrowing deeply into the plug. Dissections showed less superparasitism by the ovipositing females. In larvae collected in the field 2 or 3 *Pristomerus* eggs were sometimes found, but no heavy superparasitism was noted.

After being exposed to ovipositing females the apple-plug trays were removed and the larvae dissected out of the apple. Parasitised larvae could be distinguished by the easily visible black parasite eggs. These larvae were then placed with apples in boxes for the further development

of the *Cydia* larvae and their contained parasites. Several hundred parasitised larvae, placed on apples in this way were being reared. The life history was found to agree with the description given by Rosenberg (1934).

In 1939 the first emergence record for *Pristomerus* was 24th July, and the spring generation began to emerge on 7th April, 1940. Hence the life-cycle is about $3\frac{1}{2}$ months to the summer generation, including 3 to 4 weeks after emergence as a pre-oviposition period before suitable hosts are available. A single specimen emerged in September, 1939, and several others between this month and March, 1940, from hibernating material. Hence, in the south of France, there are two generations of *Pristomerus*, with a few odd individuals emerging during the winter.

The stages in which the insect hibernates are interesting. Hibernation occurred most commonly in the young larval stage, probably the first stage, within the host. Several such larvae were found in dissections of hibernating *Cydia* larvae. The larvae feed up quickly in the spring, discard the empty host skins, and spin their cocoons. This occurs about a fortnight before the pupation of unparasitised *Cydia* material, and gives a simple method of separating material parasitised by *Pristomerus* from the remainder. Although this is the most usual stage for hibernation, throughout the winter there have been found in the field in the south of France *Pristomerus* cocoons from which adults have emerged in the spring. Also from a cocoon taken from a quince tree on 18th October, 1939, there emerged, on 16th November, a female *Pristomerus* which hibernated as an adult, and lived 144 days until 18th April, 1940. Hence this species can overwinter in several stages.

It was found to be parasitised in the cocoon by:—

*Hemiteles* sp.
*Dibrachys cavus* Walk.
*D. affinis* Masi (only in laboratory experiments);

and in the larval stage by:—

*Perilampus tristis* Mayr.

*Trichomma enecator* Rossi (*Ichneumonidae, Ophioninae*)

A full host list is given by Rosenberg (6), in addition to which it was reared from pine shoot moth (*Rhyacionia buoliana* Schiff.) material taken in the south of France in 1940.

This species was much rarer than *Pristomerus*, and was found in *Cydia* material from apples, pears, and quinces. Here it constituted about 1% of the emergents. It also emerged from a pupa of *Rhyacionia buoliana*.

Emergence from "forced" material occurred at the same time as, or slightly before, that of *Pristomerus*. Only 5 males emerged out of a total of about 20 individuals. At room temperature both sexes lived for about 5 weeks, and, as with *Pristomerus*, there is an enforced pre-oviposition period before suitable hosts are available.

Copulation was observed several times, in all cases some days after emergence. There was no preliminary courtship before mating; the males flying in the cage suddenly alighted on the females' backs, and copulation occurred immediately, lasting for about an hour.

For oviposition females were placed in cages prepared as for *Pristomerus*, with day-old *Cydia* larvae in the apple plugs, whole apples containing larvae being also present. As in the case of *Pristomerus*, all traces of the larvae were carefully examined with the antennae, and attempts were made to parasitise the young larvae. The abdomen was considerably arched so as to bring the short ovipositor under the head whence it was thrust into the hole left by the *Cydia* larva on entering the apple. The short ovipositor is supplemented by the long abdomen, which is thrust into the larval tunnels in the excited efforts of the female to sting the host. Several larvae were dissected but no eggs or parasite larvae were found. Unfortunately the subsequent development could not be investigated owing to the international stitutation.

This was recorded only three times from *Cydia* material collected while still in the fruit, and emerged on 14th and 20th August and at the end of September. Thus there are two generations of this species.

*Ephialtes spp.*

Species of this genus reared from *Cydia* material by Rosenberg were identified as *Ephialtes extensor* Taschb. Subsequent re-examination of the specimens showed that there were two distinct species present. *E. caudatus* Ratz., and *E. crassiseta* Thoms. (see Perkins (4) ), but no *E. extensor* Taschb.

From hibernating material both these species were reared, together with *Ephialtes* sp. nov. since described by Perkins (5) as *E. cydiae*, and an unidentified species, which, from correspondence with Perkins, seems likely to be *E. ruficollis*, Desv. The comparative numbers of the species in the material may be judged from Table 3, which gives those *Ephialtes* emerging from a part of the hibernating cocoons.

Table 3.—Emergents from ecto-parasite cocoons

| *E. caudatus* | *E. crassiseta* | *E. ruficollis* | *E. cydiae* | *Cryptus* | *Hemiteles* (ex *Cryptus*) |
|---|---|---|---|---|---|
| 32 (17♂ 15♀) | 2 (2♀) | 2 (2♀) | 5 (5♀) | 27 (5♂ 22♀) | 20 (♂ 14♂) |

From this it is seen that by far the most common *Ephialtes* species was *E. caudatus* Ratz. Collections of adults on the wing in the autumn showed that *Ephialtes cydiae* Perk. is also common. The other two species must be considered rare.

*Ephialtes spp.* were found on apples, pears, and quinces, but not on walnuts. However, more extended collections would probably have found them here. *E. ruficollis* Desv. was found only on quince. The percentage occurrence of *Ephialtes* is seen in Table 4, where, owing to the impossibility of separating the larvae of the species without microscopic examination, all species are placed together. In the diagram giving times of emergence (Figure 1), they have also been placed together, as they emerge at about the same time, the latter half of April.

Attempts were made to breed all four species, and the results are given below under each species separately.

*Ephialtes caudatus* Ratz. As for the following species, exact figures for the length of adult life are not available, nor are the exact number of eggs laid per female. However, *E. caudatus* was found to have a length of life in agreement with that given by Rosenberg for *E. "extensor,"* i.e. males about 4 to 5 weeks, females about 7 weeks. Copulation was observed many times, and females mated immediately on emergence from the cocoon (cf. Rosenberg). A pre-oviposition period of about a week to a fortnight followed this.

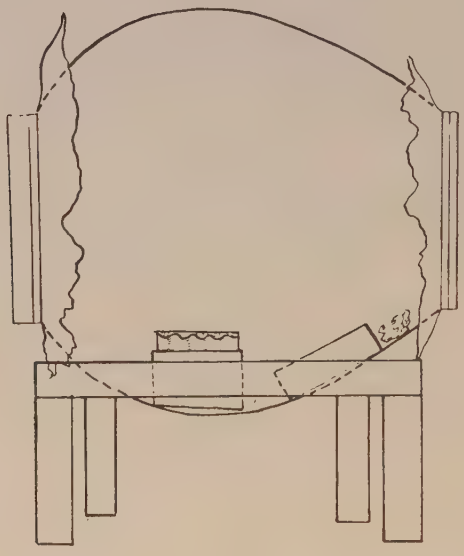

FIGURE 3. Oviposition cage used for breeding *Ephialtes* and *Cryptus* showing muslin ends to the glass cylinder, honey-water dish, and *Cydia* cocoons.

After mating, females were isolated in cages for oviposition (see Figure 3). These cages were glass shades for oil-lamps with both ends covered with muslin; they contained dishes of honey-water and raisins and also 10 *Cydia* larvae hibernating in cocoons made in strips of corrugated cardboard. These latter were placed in a small cardboard "pill-box" and arranged so that they were available for parasitisation. Each day the cocoons were examined, and those which had been parasitised were replaced, the number of eggs laid being recorded. Stinging and paralysis of larvae occurred for some days before actual oviposition took place. The acts of stinging and oviposition were as described by Rosenberg for *E. "extensor;* the number of eggs laid, and presence of collapsed eggs, was also in agreement with his figures. Throughout the oviposition period eggs were laid steadily at the rate of 2 to 3 per diem. Then, after a few days in which no eggs were laid, the females died. Great variation occurred in both the length of life and number of eggs laid per female. Also during oviposition the ovipositors of several females were snapped off, either accidentally broken whilst egg-laying, or else bitten off by the struggling *Cydia* larva.

Superparasitism frequently occurred, no apparent discrimination between healthy and parasitised larvae being shown. Two or more eggs were even laid during single attacks. In these cases, the first larva to hatch destroys the other eggs, or else the stronger larva kills the other larvae during the first stage, and only one develops per host. Development at 25° C. was the same as that given by Rosenberg for *E. "extensor"*; i.e. egg stage about 1 day, 6 days for the 5 larval stages until cocoon formation, 2 days forming the cocoon, and then 12 to 13 days until emergence; in all about 3 weeks for full developmental time.

*E. crassiseta* Thoms. Only a few individuals of this species were reared and only 3 jars set up as above. Oviposition was poor, and the length of life less than in the preceding species. Development was similar to that of *E. caudatus* Ratz., as far as it was studied, although the life cycle was not completed. In one case this species was found in the field parasitic on an *Ephialtes* larva. The "hyperparasite" was reared, and a female emerged which had developed on a larva of its own genus.

*Ephialtes ruficollis* Desv. Only 3 females of this species were obtained from *Cydia* cocoons on quince trees. These females were unmated, lived about 4 weeks in the oviposition jars, and died without laying.

*Ephialtes cydiae* Perk. Emergence of this species occurred somewhat earlier than that of the other species of *Ephialtes*. Only 2 males emerged out of about 25 individuals. Mating was observed, but only some days after emergence. However, on 6th June, 1939, numerous males of this species were seen flying round an apple tree at Aubord (Gard), presumably waiting for the emergence of females from their cocoons. These males were undoubtedly the parthenogenetic progeny of females which emerged earlier in the spring.

Eight jars were set up as before for oviposition. There was a pre-oviposition period as in *E. caudatus* Ratz., length of life was similar, and there was a period at the end of the life of the female when no eggs were laid. Fewer eggs were laid by this species than by *E. caudatus* Ratz., but this may be due to the possible unmated condition of the females. Superparasitism and development were similar to those in *E. caudatus* Ratz.

A comparative study of the various stages of the species of *Ephialtes* was started, and drawings made where possible (not of *E. ruficollis* Desv.). The egg of *Ephialtes cydiae* Perk. differed from those of *E. crassiseta* Thoms. and *E. caudatus* Ratz. which were indistinguishable. Head capsules of freshly emerged larvae were different in the three species, as were the heads of the full-grown larvae, particularly as regards the labial ring. As far as could be followed, the development of the three species was similar.

All the species emerge in the spring some three weeks before their host. In the field oviposition was observed in April, the spring generation of *Ephialtes* attacking the hibernating *Cydia* cocoons. Owing to the long life of the female parasite the spring generation is also able to attack the first generation of *Cydia* larvae in early June, which generation is also attacked by the progeny of the earlier emergents of the *Ephialtes* spring generation.

There is, therefore, considerable overlap in the parasite generations. What occurs during the summer is as yet unknown, but presumably

parasites attack the first generation cocoons, and also the hibernating cocoons in August. Adults have been seen ovipositing from September to December, 1939. The winter may be passed as the young or fully-grown larva; and in *Ephialtes cydiae* possibly as the adult, since adults were seen flying in November, and although many of this species were on the wing in the autumn, the percentage emerging from hibernating material was small. Some of the hibernating larvae seem to be in a diapause, which cannot be broken by rise in temperature; however, the majority are not so, and rise in temperature causes development to proceed normally; hibernation in this case is due only to the fact that the temperature is insufficient for development, which is usually arrested in the late larval stage.

Species attacking *Ephialtes* cocoons were:

*Hemiteles* sp.
*Ephialtes crassiseta* Thoms.
*Dibrachys cavus* Walk.

*Cryptus sexannulatus* Grav. (*Ichneumonidae, Cryptinae*)

This species was quite common in hibernating material. Males were few, as is seen in Table 3. Cocoons were found on trees of all the fruits bearing the host. Emergence occurred at the same time as *Ephialtes*, that is, about 3 weeks before *Cydia;* under natural conditions emergences started on 13th April, 1940 (*Cydia*, 1st May).

Females were placed in jars for oviposition, set up as for *Ephialtes*. A pre-oviposition period of about 10 days occurred, during which host larvae were paralysed but no eggs laid on them. After this eggs were laid regularly, at the rate of 3 to 4 per diem, until 50 to 60 (maximum) had been deposited, superparasitism occurring as with *Ephialtes*. Following this there was usually a period in which no eggs were laid, and the female died. From the first females only male progeny was reared. At 25° C. the egg stage lasts about 2 days, the larval period before cocoon formation about 6 days, and males emerged some two weeks after this. Thus the life cycle is about 3 weeks. Males thus bred were placed with females and copulation was frequently observed, but no adult progeny was obtained from these females, owing to the cessation of the work. The length of life of the female was over 7 weeks, the average of that of the males 4 to 5 weeks.

It would seem that females emerging in the spring oviposit on hibernating *Cydia* larvae, giving rise to progeny consisting predominantly of males; these then fertilise the original females to produce a later bisexual generation. As with *Ephialtes*, the course of generations during the summer is unknown, but it is highly probable that the species can parasitise *Cydia* larvae throughout this period. The autumn generation gives rise to larvae which hibernate when fully-grown.

In the oviposition jars, *Cryptus* stung and oviposited on pupae as well as larvae of *Cydia*. The larvae hatching from eggs thus laid, started feeding at intersegmental joints, where the cuticle was thin. Many of these larvae did not complete their development, but a few managed to do so. This clears up a point mentioned by Rosenberg who was puzzled at finding a *Cryptus* cocoon associated with *Cydia* pupal remains.

Species found parasitising *Cryptus* cocoons were:

*Hemiteles hemipterus* F.
*Hemiteles* sp.
*Dibrachys cavus* Walk.
*Perilampus tristis* Mayr.

*Ascogaster quadridentatus* Wesm. *(Braconidae, Cryptogastrinae)*

A full host list is given by Rosenberg (6).

This was a common species in the hibernating material from all fruits, and, as shown in Table 4, the parasite larvae have the effect of arresting the development of the *Cydia* larvae before they reach their maximum size. Hence in hibernating material the percentage of parasitism by this species is much higher amongst the small larvae than amongst the large.

This species emerged at the same time or somewhat after the main body of *Cydia*, about mid-May. The length of life was determined, but apart from this no work was done on *Ascogaster*.

This was the most common parasite found in the young larvae of *Cydia*, and it was found in all localities investigated. In young larvae from fruit, the percentage parasitised was much greater than that found by Rosenberg in hibernating *Cydia* larvae.

The first generation of *Ascogaster* emerges before June and emergents recorded were:

| July | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 23 | 23 |
| 1♂ | — | 1♀ | 1♀ | 3♀ | 4♀ | 3♂ 2♀ | 1♂ 2♀ | 3♂ 2♀ | 1♂ 1♀ | — | 3♀ | — |

| August | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 25 | 26 | 27 | 28 | 28 | 30 | 31 | 1 | 2 | 3 | 4 | 5 | 6 |
| 3♀ | — | — | 1♀ | — | — | — | 2♀ | — | 4♂ 2♀ | 2♂ 1♀ | 1♂ | — | 1♂ |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| — | 1♂ | 1♂ | — | 2♂ | 1♂ | — | 1♂ 1♀ | 3♀ | 1♀ | 2♀ | 1♂ | 1♂ | — | 2♂ |

| November | |
|---|---|
| 22 | 27 |
| 1♂ | 1♀ |

It seems that there are three generations with a partial fourth. The very late emergents may hibernate over winter, since unless there are alternate hosts available, it is difficult to see where oviposition could occur.

Parasites:

*Dibrachys cavus* Walk.
*Perilampus tristis* Mayr.

*Meteorus? chrysophthalmus* Nees *(Braconidae, Polymorphinae)*

As before, Rosenberg (6) gives a full host list of this species.

Specimens of a primary parasite of *Cydia*, thought to be this species, emerged from material from several localities, particularly from that from walnut trees at Grenoble. Emergence occurred at the same time as *Ascogaster*. There were only a few individuals and no mating was observed; and, although supplied with *Cydia* larvae in various stages, females made no attempt to parasitise them.

*Arrhinomyia tragica* Mg. *(Tachinidae)*

Only 3 specimens of this species were obtained from thousands of hibernating larvae. These were supplied with *Cydia* eggs and young larvae, but no parasitism occurred; fully-grown larvae were also supplied, without success. Owing to the small number of adult parasites available, attempts to breed them were discontinued. It seems possible that the species may attack fully-grown larvae when they leave the fruit to form their cocoons, although microtype eggs are laid, of the type usually laid on the food and ingested by the larvae.

Secondary Parasites

The following species were reared from *Cydia* material, but were secondaries, or at the most only occasionally primarily parasitic on *Cydia*.

*Hemiteles spp. (Ichneumonidae, Cryptinae)*

There were at least three species of *Hemiteles* bred from *Cydia* cocoons, and these included alate and brachypterous forms; the systematics of the group are, however, greatly confused, and exact determinations of the species are difficult.

*Hemiteles spp.* were reared from:

*Pristomerus vulnerator* Panz.
*Ephialtes sp.*
*Cryptus sexannulatus* Grav.

Rosenberg (6) gives the host list of *H. hemipterus* F. and deals briefly with the life history of this species, and also that of *H. macrurus* Ths. *Hemiteles* spp. were found naturally only as secondary parasites, but 1 adult was reared through from an egg which had been laid on a *Cydia* larva, on which larvae oviposition readily occurred in the laboratory. It seems possible that, under natural conditions, a number of *Cydia* larvae are paralysed and killed by these parasites.

By far the greater number of *Hemiteles* emerged from *Cryptus* cocoons, and from Table 3 it is seen that from part of the *Cydia* material emerged 5 males and 22 females *Cryptus* and 6 males and 14 females *Hemiteles*—i.e. 42.5% parasitism of *Cryptus*. Only in one case did the species emerge from a *Pristomerus* cocoon.

Emergence occurred long in advance of all other species, commencing on 23rd March, 1940. The species are long lived, and can therefore attack a large number of hibernating parasite larvae before these metamorphose in the spring. Even without this spring attack it is seen that 42.5% of the *Cryptus* cocoons are parasitised. Hence, in the absence of *Hemiteles*, the control of *Cydia* by *Cryptus* would perhaps be greater.

*Perilampus tristis* Mayr. *(Chalcidae, Perilampidae)*

Perilampids reared by Rosenberg (6) from *Cydia* material were identified as *P. tristis* Mayr. and *P. laevifrons* Dalm. He did not investigate the life-history of the species. Subsequent examination of the same material showed that only one species, *P. tristis* Mayr., was present, and all the material reared in this work belongs to the same species. Planidia

(Figure 4) were found in the young *Cydia* larvae dissected in the early summer. They were found in otherwise unparasitised *Cydia* larvae, and also in host larvae already parasitised by *Ascogaster* and *Pristomerus*.

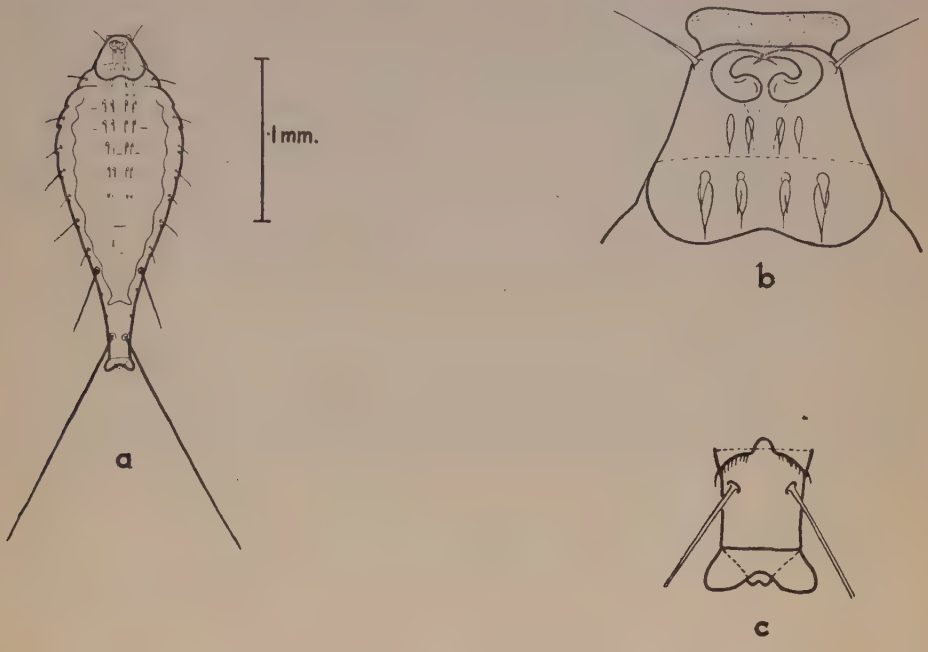


FIGURE 4. *Perilampus tristis* Mayr. (a) planidium, (b) anterior end, (c) posterior end (long setae not shown in full).

When unparasitised hosts are attacked by *Perilampus*, and no further parasitism occurs, the Perilampid larvae die; they only survive when further parasitism occurs, and are true hyperparasites, parasitising the primary parasites of *Cydia*. Superparasitism is common, as many as 8 panidia having been found in a single *Cydia* larva, although only 1 *Perilampus* emerges from the cocoon of the primary parasite.

The life history of *Perilampus* has been fully worked out by Smith (8), Bergold and Ripper (1), and is mentioned by Boyce (2). *Perilampus* eggs are laid on the apple foliage and fruit, and the highly mobile and sclerotised planidia, which were found to move by movements similar to those of a geometrid "looper" larva, enter the first stage codling moth larva as it wanders around before entering a fruit. Here the planidia remain without change until further parasitism occurs (the host larva may, of course, already contain an *Ascogaster* larva) and then, when the primary parasite larva begins to feed, with the consequent destruction of the host, the Perilampid planidium enters the parasite larva. When the latter is fully grown and has spun its cocoon, the planidium bores to the exterior and feeds ecto-parasitically on the parasite larva, pupates, and eventually emerges from the parasite cocoon. This species has also been seen to emerge from *Cryptus sexannulatus* cocoons. In this case the primary parasite is an ectoparasite, and the planidium must move from the paralysed

*Cydia* larva into the ecto-parasitic *Cryptus* larva and continue its development from this point (it has also been found in Canada to be parasitic on another ecto-parasite of *Cydia—Aenoplex carpocapsae* Cush.).

The hosts from which *Perilampus* emerged were:

*Ascogaster quadridentatus* Wesm.
*Pristomerus vulnerator* Panz.
*Cryptus sexannulatus* Grav.
(*Chrysopa* sp. . ? Secondary parasite).

Of 194 parasites emerging from a number of collections of larvae, 16 were *Perilampus;* hence 8% hyperparasitism occurred. The number of *Perilampus* emerging from *Ascogaster* cocoons was greater than that from *Pristomerus*, but this was only due to the relative abundance of these two parasites, since the *Perilampus* attack on the host is entirely independent of the other two species.

In the spring *Perilampus* was found to emerge some time after all the other parasites (see Figure 1), well at the end of the *Cydia* emergence period. As stated above, planidia were found in first stage *Cydia* larvae during dissections, and numerous specimens emerged from material collected while the *Cydia* larvae were still in the fruit. Emergence occurred:

| July | | | | | | August | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 27 | 28 | 29 | 30 | 31 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | — | 1 | — | — | 1 | 2 | — | 1 | 1 | — | — | — | — | — |

| August | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| — | 1 | 1 | — | 3 | 3 | — | 3 | 2 | 3 | 2 | — | 1 |

| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|
| 1 | — | — | 1 | — | — | — | — | — |

| September | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7-11 |
| 1 | — | 1 | — | 1 | — | 1 |

and there are thus at least two generations during the year. This species, by destroying a number of primary parasites, lessens the degree of biological control of *Cydia*, and this effect will be discussed later.

*Dibrachys affinis* Masi *(Chalcidae, Pteromalidae)*

A host list is given by Rosenberg (6) who reared this species from *Cydia* pupae. In the present work it was reared from the following two hosts:

*Cydia pomonella* L.
*Pristomerus vulnerator* Panz.

This species was not found as a secondary parasite in the field, but it was thought best to include it here since it did, in the laboratory, parasitise *Pristomerus* cocoons. It was reared from *Cydia* pupae found in "bands," and was not strictly from hibernating *Cydia* material, since only the pupal skin of the host remained, filled with full-grown larvae of the parasite. No diapause occurred, and cessation of development over winter was caused only by low temperature. In the "bands" hibernating adults were also found.

A number of experiments were conducted with this species, which are described below with similar experiments with *Dibrachys cavus* Wlk.

*Dibrachys cavus* Walk. *(Chalcidae, Pteromalidae)*

This common gregarious Chalcid has been recorded from a wide range of hosts. According to Rosenberg (6) "in the card index of the Farnham House Laboratory are records of its occurrence on: 11 species of Ichneumonidae, 16 species of Braconidae . . . . . , 2 species of Chalcididae, 3 species Tenthredinidae, 1 species of Lepidoptera . . . . , 3 species of Coleoptera and 1 species of Neuroptera." He then mentions the fact that he bred it in the laboratory on pupae of *Cydia pomonella* L.

In the present work, both *Dibrachys cavus* and *D. affinis* Masi were reared, the latter only as an endoparasite of *Cydia* pupae, although in the laboratory it was bred ecto-parasitically on the larvae of *Pristomerus vulnerator*, Panz. The former Chalcid was an endoparasite of *Cydia* pupae, an ecto-parasite of full-grown *Cydia* larvae in their cocoons, and an ecto-parasite of larvae, prepupae, and pupae of the *Cydia* parasites—*Ascogaster quadridentatus* Wesm., *Pristomerus vulnerator* Panz., *Ephialtes caudatus* Ratz., *E. crassiseta* Thoms., *E. cydiae* Perk. and *Cryptus sexannulatus* Grav.

In the cases where *D. cavus* is a secondary parasite the eggs are laid on or near the Hymenopterous larva, prepupa or pupa within the cocoons (of the *Cydia* larva or parasite according to the stage attacked), and the young larvae feed gregariously through the skin of the host. However, when primarily parasitic on *Cydia*, *D. cavus* exhibits two forms of parasitism: (1) it is found as an ectoparasite of fully-grown larvae within their cocoons, the larvae being paralysed before oviposition; and (2) as an endoparasite of the pupae—(also noted by Boyce (2) ). This peculiar behaviour was thought worthwhile investigating, and experiments were started in order to determine the host preferences of the ovipositing *Dibrachys* females, and also to ascertain whether there is anything of the nature of two biological races of the chalcid, one ecto- and the other endo-parasitic.

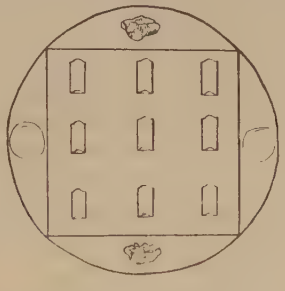

FIGURE 5. Petri dish with alternating *Cydia* and *Pristomerus* cocoons used in the host selection experiment with *Dibrachys*.

For host selection experiments different types of hosts were stuck with gum tragacanth alternately at regular intervals (as in Figure 5) on a piece of card, which was placed with *Dibrachys* adults in a petri dish and kept at 25° C., raisins and water being supplied for the adult parasites.

The hosts offered consisted of *Cydia* larvae and pupae, and cocoons of *Pristomerus vulnerator* containing larvae or pupae. All these were in the original *Cydia* cocoon, and this in turn was left in the small section of corrugated cardboard in which it had been spun.

Dishes were prepared with *Cydia* larvae alternating with pupae; others with *Cydia* larvae and *Pristomerus* cocoons. Four of each type were prepared, and into each were introduced 5 female and 5 male freshly emerged *Dibrachys cavus* adults, reared from ecto-parasites of *Cydia* larvae. The hosts attacked, and those from which progeny emerged were recorded. These experiments were then repeated but using adults bred endo-parasitically from *Cydia* pupae; and finally again with *Dibrachys affinis* bred from *Cydia* pupae, and ecto-parasitically from *Pristomerus* larvae.

Unfortunately, all the detailed results of these and the following experiments are not available, since as stated above, they were lost during the French collapse of June, 1940. However, the final results were quite definite.

*D. affinis* attacked and parasitised *Cydia* pupae and *Pristomerus* cocoons even when the latter contained far advanced pupal stages. It never attacked *Cydia* larvae in their cocoons. On the other hand *D. cavus*, whether reared ecto- or endo-parasitically, attacked *Cydia* larvae and *Pristomerus* cocoons for preference, either being equally acceptable. If no other hosts were available the females parasitised *Cydia* pupae and the larvae developed endo-parasitically.

The above experiments indicate that *D. cavus* is not composed of two biological races—one with a preference for *Cydia* larvae as hosts, and the other for *Cydia* pupae. However, it was thought worth while investigating whether some preference for *Cydia* pupae might develop if *Dibrachys* were bred continuously on this host for a number of generations. A strain of *D. cavus* was bred on pupae for several generations and further host selection tests made. No such modification of host preference was recorded, and there was no influence exerted by the larval environment on the choice of host by the ovipositing female, which always showed a preference for *Cydia* larvae.

Thus the larvae of *D. cavus* and *D. affinis* can develop as endo-parasites, eggs being laid within the tissues of *Cydia* pupae, and also as ecto-parasites, the larvae feeding, in the case of *D. cavus*, externally on fully grown *Cydia* larvae, and larvae and pupae of several species of parasites; and in the case of *D. affinis* on various stages of *Pristomerus*. When *Pristomerus* cocoons were used as hosts, *Dibrachys* larvae were able to develop, not only on far advanced pupae, but also on the resting adults, when the soft abdominal tissues were consumed, the hard sclerotised parts remaining.

Imms (3) states "The factors that determine whether a species lives within or external to its host are evidently fundamental, since the endo-parasitic mode of life involves a complete change in methods of respiration." The behaviour of *D. cavus* and *D. affinis* in this repect show that this statement is not always true, and the small size and apneustic condition of the young *Dibrachys* larvae permit of this internal feeding without any special respiratory adaptation. When larger, the endo-parasitic larvae within the host pupa have, no doubt, by the destruction of part of the host

tissues, formed air spaces sufficient for their respiratory requirements. There seems to be no other difference between the endo-and ecto-parasitic habit that would affect the physiology of the parasite larva, and it would be interesting to see if this facultative change of method of larvae feeding is of common occurrence.

*Melittobia acasta* Walk. *(Chalcidae, Eulophidae)*

The occurrence of this species from a *Cydia* pupa has already been recorded (Simmonds (7) ). Four males and 7 females of *Melittobia* and 3 males and 13 females of *Dibrachys affinis* Masi emerged from a single *Cydia* pupa. It seems probable that the *Cydia* pupa was attacked first by the *Dibrachys*. Then, by the action of these endo-parasitic larvae in causing disruption of the host tissues and, consequently, air spaces, it was rendered suitable as a host for *Melittobia*, and was then attacked by this species.

## ARTIFICIAL REARING OF PARASITES

It was thought possible that, once having obtained parasite eggs, it might be feasible to rear the larvae on artificial nutritive media. In eliminating the necessity for natural hosts, this would be of great use in large-scale breeding.

Owing to the difficulties presented by rearing endo-parasitic larvae thus, due to the respiratory requirements of the larvae, it was decided to experiment with ecto-parasites. A number of eggs were available from *Cydia* larvae superparasitised by *Ephialtes* sp., and *Cryptus*. Gelatine slopes were prepared (partly by Professor Urbain of Paris) of various compositions, and pieces of meat were also used. Parasite eggs placed on the media hatched normally, and the first stage larvae fed and grew. However, only in one case did moulting take place; the first stage larvae reached their normal maximum size and then died, as if some substance that promoted moulting was lacking from their diet. Dampened raw beef steak proved to be the most acceptable of the media tried, and it was on this that the one case of moulting occurred. It is hoped that further more extensive work on this problem will be done in the near future.

## BIOLOGICAL CONTROL

In the South of France the percentage of parasitism of the various stages of *Cydia* was everywhere (except in the case of *Arrhinomyia tragica* Mg.) higher than those recorded by Rosenberg. A consideration of the percentages of the pest that are destroyed by parasite species shows that the total destruction they cause must be considerable. It is of interest to follow the codling moth through its annual cycle in the South of France, and try to estimate the effect of parasitism. It will be convenient to start with the eggs of the first summer generation which occur in the field after the middle of May. No egg parasites of the *Trichogramma* type were found, since work was commenced too late in 1939 and was stopped in 1940 before this could be adequately investigated. Sheets of waxed paper on which there were *Cydia* eggs were hung in apple trees in May, 1940, but no parasitism was observed. However, doubtless a certain amount of parasitism does occur.

Dissections of young larvae showed a total parasitism (excluding larvae parasitised by *Perilampus* alone) of 37.5%, 33.1% were parasitised by *Ascogaster*, 6.4% by *Pristomerus*, there being an overlap of these two species in 2% of the hosts, which had been attacked by both species. *Perilampus* attacked 3.7% of the total larvae, or 6.0% of the parasitised larvae.

Figures from the emergence records of this generation show 17.3% parasitism by *Ascogaster*, 4.1% by *Pristomerus*, 0.8% by *Trichomma* and 9.5% by *Perilampus*. *Trichomma* appears to be comparatively unimportant, and it is seen that *Perilampus* reduces considerably the number of emergents of *Ascogaster*. Since the material was removed from the field when the host larvae were young, it is possible that in the field the percentage parasitism by *Pristomerus* and *Trichomma* is greater than is indicated here.

Thus of these first generation larvae between 30% and 40% are parasitised before they spin their cocoons, chiefly by *Ascogaster*, the efficiency of which as a controlling agent, is considerably reduced by *Perilampus*.

Of these first generation larvae only about 50% emerge to give the second generation of *Cydia* in the summer, the other 50% remain as hibernating larvae within their cocoons until the following spring. Both hibernating cocoons and those which are to produce the second generation adults are subject to parasitism by *Ephialtes*, *Cryptus*, and *Dibrachys*, which further reduces the numbers of *Cydia* by about 10% of the now unparasitised larvae (or about 6% of the total larvae).

Thus, of the eggs laid by the spring emergents of *Cydia* about 50% go into hibernation (30 to 40% parasitised) until the following spring. The remaining 50% produce both parasites and hosts for a second generation, with a final result that under 20% of the original number of eggs laid produce adult *Cydia* in the summer generation; this does not, of course, take into consideration loss due to disease, predators, etc.

This second generation emerges in July and August, and there is a partial third generation in September, although the majority of the larvae from this second generation enter diapause and hibernate until the following spring. The eggs of this generation are again presumably parasitised by egg parasites; and figures from hibernating material show to what extent the larvae of this generation are parasitised. This shows that taking the collections as a whole 5.7% of the larvae were parasitised by ecto-parasites, and that of the remaining larvae about 32.7% were parasitised by endo-parasites (13.0% *Ascogaster*, 15.4% *Pristomerus*, 4.3% *Perilampus*). *Trichomma*, *Meteorus*, and *Arrhinomyia* only occurred in small numbers. Thus *Ascogaster* and *Pristomerus* are equally important as controlling agents, the efficiency of both being reduced by hyperparasitism by *Perilampus*.

Of the ecto-parasitism of 5.7%, 2.8% was by *Ephialtes*, 1.4% by *Cryptus*, 0.4% by *Dibrachys*, and 1.1% stung but not parasitised. From Table 3 it is seen that out of 47 cocoons of *Cryptus*, 27 *Cryptus* and 20 *Hemiteles* emerged, or that the numbers of *Cryptus* in the succeeding generation were reduced by 42.5% by the action of the secondary parasite.

As is seen from the emergence diagram (Figure 1) the ecto-parasites emerge in the spring some time before *Cydia*, and consequently further parasitism of hibernating material by the ecto-parasites occurs in the spring in addition to that recorded here—(and, incidentally, further secondary parasitism by *Hemiteles*).

To summarise; the first generation larvae in May are parasitised to the extent of 30% to 40%, together with 10% parasitism by ecto-parasites, and half of these go directly into diapause until the following spring, not emerging as moths in the 2nd generation. In the 2nd generation similar parasitism occurs, and in the spring hibernating host material is again attacked by ecto-parasites.

Thus it is seen that considerable parasitism occurs throughout the season. However, this parasitism was insufficient during the period of the investigation to prevent nearly all suitable fruit from being attacked.

The hyperparasite *Perilampus* and the secondary parasite *Hemiteles* are seen to cause considerable reduction in the numbers of emerging parasites, and it is possible that if not subjected to this restraint, the parasites might be able to exert greater control. *Perilampus tristis* Mayr. already occurs in Canada, as does *Ascogaster*, hence this part of the codling moth parasite complex is already established in that country.

It was thought that *Pristomerus*, *Ephialtes*, and *Cryptus* should be introduced, together, if possible, with *Trichomma*, *Arrhinomyia*, and *Meteorus*. *Dibrachys cavus* already occurs in Canada and *Dibrachys affinis* Masi is of doubtful value in view of its tendency to become a secondary parasite. In the case of *Cryptus* it was hoped that if it could be established in Canada without the check of *Hemiteles* it might become a successful agent in the control of the codling moth.

When the international situation became more difficult, a small shipment of *Cryptus sexannulatus* Grav. and *Ephialtes caudatus* Ratz. was made to Canada, and these species have been reared in the Dominion Parasite Laboratory, at Belleville, and liberations have been made in the Niagara peninsula in Ontario, although it is, as yet, too early to estimate their value as controlling agents.

## SUMMARY

The species of parasites and predators attacking the various stages of the codling moth, *Cydia pomonella* L., in the South of France have been reared and their biology investigated.

Experiments were set up to determine whether fruit in any particular part of a tree was more liable to attack by *Cydia* than another, and whether at any part the degree of parasitism was higher. The influence of variety of fruit on parasitism and hibernation was also investigated.

The host preferences of one of the parasites, *Dibrachys cavus* Walk. were tested, in view of the peculiar behaviour of this species which can be either ecto- or endo-parasitic, according to its host.

The degree of biological control exerted is discussed, and recommendations made as to which species of parasites should be shipped to Canada to control the codling moth there.

## ACKNOWLEDGMENTS

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# THE EFFECT OF HEAT, INSULATION AND ARTIFICIAL LIGHT ON EGG PRODUCTION AND FEED CONSUMPTION OF PULLETS[1]

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Increasing the physical comfort of laying birds under both extremes of environmental temperature has very often been the subject of investigation. Protection against extreme cold has naturally been a problem of greater economic importance, however, and most controlled research has been in that direction. Artificial heat, insulation and the provision of adequate ventilation under varying conditions have been the principal subjects of experiment. The first large scale and most notable experiments on artificial heating and insulation were reported by Smith (7). His principal conclusions which bear on the work here reported were that insulation had a beneficial effect upon winter egg production; whereas the application of moderate heat was of doubtful value in this respect, and that humidity in the pen and winter egg production were not correlated. It is interesting also to note his finding that "closing a house up tightly all night during the winter period had no detrimental effect on winter egg production." Bruckner (2) reported heating to 50° F. to have a stabilizing effect upon winter egg production and to produce a non-significant but consistent small increase therein. A temperature of 60° F. affected health, body weight and egg size adversely and the use of temporary heat during cold spells did not increase winter egg production significantly. Of particular interest to the work to be reported was the statement that "laying hens in heated houses require less feed to produce a pound of eggs than those in unheated houses." No statement is made as to the amount of saving brought about. Lee (4, 5) after two years work states "the use of supplementary heat in an insulated laying house under the climatic conditions of Central New York State results in a lower annual egg production . . . ." While the great variability experienced between replicate pens indicates that the fact that heat actually reduced production may have been fortuitous, it is worthy of note that in spite of very low temperatures in the unheated pens the use of heat at least did not increase production.

Conditions of temperature during the winter months are very extreme in the area represented by this institution. Table 1 shown herewith, indicates the temperature at Ottawa to be much more rigorous than at Lincoln, Nebraska and Ithaca, New York, referred to above. The last mentioned figures would also largely hold for the work done by Lee (loc. cit) at Cayuga, New York. Not only is severe cold experienced but changes in temperature amounting to 40 to 50° F. sometimes occur within a period of 48 hours. Under these circumstances the benefits of artificial heat and insulation should be evident if such exist. From the winter of 1932-33 to that of 1942-43 a series of experiments was conducted dealing with the

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[2] Agricultural Scientists.
[3] Agricultural Assistants.

TABLE 1.—A COMPARISON IN TEMPERATURE DURING WINTER 1933-34 AND OF LONG TIME AVERAGES

| Month | Ottawa* | | | Cornell | | | Lincoln | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean temp. | Normal mean | Lowest | Mean temp. | Normal mean | Lowest | Mean temp. | Normal mean | Lowest |
| | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. | °F. |
| December | 5.1 | 17.3 | −38 | 27.4 | 29.0 | −13 | 32.8 | 27.6 | −4 |
| January | 10.3 | 11.7 | −34 | 27.6 | 24.3 | − 3 | 31.6 | 22.8 | 1 |
| February | −2.7 | 12.7 | −37 | 12.8 | 24.5 | −24 | 30.2 | 26.1 | −9 |
| March | 19.9 | 24.7 | −12 | 32.2 | 31.8 | 5 | 38.0 | 37.5 | 8 |
| Mean | 8.2 | 16.6 | −38 | 25.0 | 27.4 | −24 | 33.2 | 28.5 | −9 |

* Data by courtesy of the Division of Field Husbandry, Central Experimental Farm.

effects of heat and insulation. In 1939-40 artificial light was also used in a controlled way. The present paper places the results of these tests on record.

## EXPERIMENTAL

With the exception of the experiment of 1942-43, which will be separately described, all tests were carried out in a 10-pen continuous laying house, each pen measuring 16 × 16 feet. Since it is important to establish the degree to which the birds were protected from the outside elements in the least protected pens (control pens) the following description is given and applies to all pens except for the modifications of greater insulation or artificial heat which will be noted.

*Control pens* (uninsulated): floor—concrete; ceiling—straw loft of 1″ × 3″ boards, 1″ apart under joists with 12″ of unpacked straw in loft above; roof—2″ × 4″ rafters, $\frac{3}{4}$″ sheathing, building paper and cedar shingles; rear wall—1″ tongue and groove boarding with batons, building paper on 2″ × 4″ studs, with building paper and $\frac{7}{8}$″ shiplap, making a 4″ dead air space; front wall—$\frac{1}{3}$ wood (single boarded) $\frac{1}{3}$ glass and $\frac{1}{3}$ cotton (screens), all three types of construction running the full length of the pen.

*Semi-insulated pens:* same construction as above except: ceiling—$\frac{1}{2}$″ insulation board under straw loft; rear wall—$\frac{3}{4}$″-V joint over $\frac{1}{2}$″ insulation board built over shiplap of inner wall lining; front wall—1″ boarding with batons, 2″ × 4″, sheathing and $\frac{3}{4}$″-V joint over $\frac{1}{2}$″ insulation board on studding under windows; glass substitute (cel-o-glass) replaced cotton screens.

*Insulated pens:* same as semi-insulated pens except: front wall—$\frac{1}{3}$ glass and $\frac{2}{3}$ wood ($\frac{3}{4}$″-V joint over $\frac{1}{2}$″ insulation board—no cotton or cel-o-glass screens).

Tightly boarded, insulated partitions separated uninsulated pens from semi-insulated and these in turn from insulated pens. Replicate pens within the above were separated by reasonably tight temporary partitions.

In terms of insulation as estimated from data published by Moore and Bell (6) and by Jones (3) the uninsulated pens had back and side walls of approximately 4.14 insulating value, whereas the semi-insulated and insulated pens had walls of 6.65 insulating value. The insulated pens, however, had the benefit of 6.65 insulating on the front wall over $\frac{2}{3}$ of the

front area, whereas the semi-insulated had such insulation over only $\frac{1}{3}$ of the front wall. The uninsulated pens had a $\frac{1}{3}$ front wall area of insulating value of 1.53, the remainder being glass and cotton of very low insulating value. Ceiling insulation was identical for the insulated and semi-insulated pens ($\frac{1}{2}''$ insulation board) but much lower for the uninsulated pens with straw loft. The hinged ventilating doors at each end of the house over the straw loft were kept closed throughout thus making a dead air-space of the loft.

The nature of the heat supply will be dealt with under separate headings. Temperatures were taken in the middle of the pen, 6″ above the floor. Night temperatures were taken at mid-level of the birds above the roosts and in amongst them, by recording thermographs except for the 1932-33 and 1933-34 experiments when floor temperatures were used throughout. Humidity was taken by recording thermohygrographs or by sling psychrometer. All ventilation was by adjustment of windows or cotton screens hinged at the bottom with side baffles thus permitting entry of air only at the extreme top front of the house. Barred Plymouth Rock pullets balanced between pens according to date of hatch were used in all experiments.

The principal criteria used to determine the comparative merits of treatments were egg production, body weight and gain or loss in the latter. By the use of Bird and Sinclair's (1) partial regressions of these characters on total feed consumption the feed required for total maintenance was arrived at, and on the basis of requirements for resting metabolism by Diakow and basal metabolism by Brody as quoted by Bird (loc. cit) requirements for activity and work of digestion were allowed for, making feed requirement for basal metabolism, which is largely heat production, 60% of total maintenance. This figure was considered to be the closest estimate which could be made for feed required for heat loss from the body and is stated as feed for maintenance of body temperature.

## RESULTS

The information gathered is shown for each year's experiments separately.

*Experiment 1932-33*

This test covered a period from November 18 to June 12. It comprised 3 pens heated with hot water pipes under dropping boards, 1 pen semi-insulated and 1 pen uninsulated. Since at that time it was thought that a smaller floor area per pullet would be required under heated conditions the 3 heated pens consisted of 75 birds each, the other 2 pens each containing 50 birds. Lowest temperatures experienced inside the pens for the different treatments were: heated 38° F., semi-insulated 27° F. and uninsulated 10° F. Lowest outside temperature was 25° F. below zero.

Table 2 shows the essential data obtained. It is immediately evident that neither heat nor insulation had any effect upon egg production, the differences being small and within the range of error of the test. It must be assumed therefore that equal opportunity for egg production exists at mean temperatures of 38.° F. or 51.2° F. Body weight gains also did not differ significantly. Feed required for maintenance of body heat did

TABLE 2.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED CONSUMPTION

| 1932-33 | No. of birds | Mean temp. | Body wt. gain | Feed consumption | Feed for maintenance of body temp. | Egg production |
|---|---|---|---|---|---|---|
| | | ° F. | gm./bird | gm./bird/day | gm./bird/day | gm./bird/day |
| Heated (3 pens) | 225 | 51.2 | 78.4 | 106.5 | 49.8 | 29.3 |
| Semi-insulated | 50 | 42.6 | 86.5 | 117.3 | 54.6 | 32.8 |
| Uninsulated | 50 | 38.0 | 90.6 | 114.9 | 53.8 | 31.3 |

not parallel pen temperature which is not surprising in view of the measure of error which is inherent in all estimates of this kind. However, the maximum increased requirement for maintenance of body heat in the coldest pen was 4.8 gm. per bird per day. Since it is the case that this saving could be made only for the winter months, or roughly 150 days, then the annual saving per bird per year would be approximately 1.6 lb. per bird. It will at once be appreciated that such a small saving would hardly justify installation of heating plant, fuel and labour costs in heating such a poultry house. Further the cost of the additional insulation of the semi-insulated pen was not justified by these data. In considering the above data it must be realized that the heavier population of the heated pens may have had an undeterminable effect upon the performance of these pens. It probably might be expected, however, to affect such factors as livability or cannibalism rather than egg production.

*Experiment 1933-34*

This experiment covered the period from November 15, 1933 to April 14, 1934, a period of 140 days. The experiment of the previous year was repeated but since temperature of the heated pens had fluctuated to a greater extent than was desirable, adjustments were made to the heating and ventilating equipment which resulted in a somewhat smaller range of temperature. It was found to be impossible, however, to keep it from slightly exceeding 60° F. when very sudden upward changes of outside temperature occurred. Lowest temperatures experienced inside the pens for the different treatments were: heated 40° F., semi-insulated 19° F., uninsulated 16° F. Lowest outside temperature was 38° F. below zero.

TABLE 3.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED CONSUMPTION

| 1933-34 | No. of birds | Mean temp. | Relative humidity | Body wt. gain | Feed consumption | Feed for maintenance of body temp. | Egg production |
|---|---|---|---|---|---|---|---|
| | | ° F. | % | gm./bird | gm./bird/day | gm./bird/day | gm./bird/day |
| Heated | 55 | 50.6 | 61 | 245 | 95.3 | 44.1 | 22.8 |
| Heated | 55 | 49.9 | 63 | 248 | 100.7 | 46.7 | 24.0 |
| Semi-insulated* | 55 | 45.6 | 86 | 245 | 103.4 | 49.2 | 22.6 |
| Semi-insulated | 55 | 43.8 | 85 | 338 | 106.3 | 50.3 | 23.1 |
| Uninsulated | 55 | 42.1 | 86 | 283 | 104.2 | 50.3 | 20.5 |
| Uninsulated | 55 | 39.1 | 87 | 500 | 113.5 | 53.8 | 24.2 |

* No ventilation.

Table 3 shows the results obtained. Approximately the same mean temperatures were experienced in the pens under the different treatments as was the case in the previous year's test. Relative humidity was recorded in this instance and showed the air to be relatively drier in the heated pens. Again no significant differences occurred in egg production. The feed required for maintenance of body temperature followed the change in temperature in the different pens to a gratifying degree, indicating a reasonably accurate estimate of feed required for this purpose to have been obtained. The temperature in the warmest of the heated pens was 10.5° F. higher than that of the coldest uninsulated pen, for a maximum saving in feed for maintenance of body temperature of 9.7 gm. or 3.2 lb. of feed per bird annually. No significant difference occurred between feed required for maintenance in the semi-insulated and uninsulated pens, and the greatest difference represents a saving of 1.5 pounds of feed per bird per year. Relative humidity obviously had no effect on any of the criteria considered.

The pen shown in Table 3 as semi-insulated with no ventilation is of particular interest. In this pen the cotton screens, which when closed are the only source of change of air, were kept closed continuously throughout the test and were covered over with insulation board so that the only ventilation which the birds received was any change of air which took place through cracks around windows and partitions between pens which undoubtedly was very small. The result as shown by the table was a warmer pen than its duplicate by 1.8° F. with a higher relative humidity by 1%. The condition of absolute humidity was much greater than is indicated by Table 3, however, since the walls and litter were continuously wet from condensed moisture and there was a heavy concentration of ammonia in the air. Carbon dioxide, determined from samples taken with mine flasks under the roosts at night was 0.73% in this pen as compared to 0.28% in one of the heated pens. Under these conditions the performance of the birds was the equal of that of any other treatment and it would appear that birds can stand low temperatures with high humidity and relatively heavy concentration of ammonia and carbon dioxide over an extended period very well indeed.

*Experiment 1939-40*

This experiment covered the period November 22 to April 10 or 154 days. In this instance fully insulated pens without heat were used for the first time. Also since no benefit had accrued when heat at 50° F. had been used it was lowered to 45° F. during the whole of this test. In addition, since the hot water system still permitted a fairly large range in temperature in the pens thus treated, thermostatically controlled electric heating equipment was installed and this reduced the variability to ± 4° F. on the average.

Lowest temperatures experienced inside the pens for the different treatments were: heated 40° F., insulated 28° F., semi-insulated 26° F., uninsulated 26° F. Lowest outside temperature was 19° F. below zero.

Table 4 shows the data obtained. An outstanding feature of these data is the higher mean temperature in the semi-insulated and uninsulated pen than was the case in the completely insulated pen. An examination

TABLE 4.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION.

| 1939-40 | No. of birds | Mean temp. | Relative humidity | Feed consumption | Egg production to March 20 | Egg production to Sept. 4 |
|---|---|---|---|---|---|---|
| | | ° F. | % | gm./bird/day | no. | no. |
| Heated | 55 | 45.3 | 81 | 129.7 | 87.7 | 195.7 |
| Insulated | 55 | 37.1 | 91 | 132.8 | 86.2 | 193.3 |
| Semi-insulated | 55 | 39.2 | 88 | 133.5 | 93.4 | 192.5 |
| Uninsulated | 55 | 37.8 | 88 | 136.0 | 89.0 | 194.4 |

of the charts from the thermographs showed the reason for this condition to be the consistently higher mid-day and afternoon temperatures in the semi-insulated and uninsulated pens on sunny days. Since the winter climate in this area is characterized by cold days with brilliant sunlight the cumulative effect of this sunlight shining through glass and glass substitute was to raise the mean temperature of these 2 pens to an appreciable degree. Since the insulated pen had been more completely insulated by substituting insulated wall for one-half the window area, the effect of the sun was not nearly so pronounced in this pen. It is significant to note that in this instance the effect of additional glass area was sufficient to nullify the effects of thorough insulation. Had the cotton screens of the uninsulated pens been replaced by glass these pens would probably have been almost as warm as the semi-insulated pens.

The egg production to March 20 or during the cold period of the year did not differ significantly for any group. At September 4, close to the end of the laying year, production was still almost identical for all groups. Sufficient data were not available to estimate feed required for maintenance in this case, but production being almost identical it may be assumed from the figures for total feed consumption that the amount used in offsetting the greatest difference in temperature of 8.2° F. was negligible.

*Experiment 1941-42*

This test covered a period from November 17, 1941 to March 22, 1942. All heating was again electrical and thermostatically controlled. Besides heating 2 groups to 54° F. and 59.9° F., respectively, 1 fully insulated group was heated at night only, by running resistance wire the full length of the under side of the roosts. It was reasoned that the warmth of sunlight and activity might bring about satisfactory conditions of temperature during the day and the relative inactivity of roosting might result in the need for some supplementary heat during the night. One other change in treatment was made, namely, that the ventilation of the semi-insulated pen was restricted in contrast to the situation in all other experiments in which (with one exception previously noted—1933-34) an attempt was made to have the same amount of ventilation in all groups. In this pen the sliding ventilators in the glass substitute screens were kept with a minimum of opening during morning and late afternoon and opened relatively wide during the warmest hours of mid-day when the sun was shining thus permitting the escape of moist air and maintaining a litter condition similar to that of comparable pens. At night the slides were closed entirely.

Lowest temperatures experienced inside the pens for the different treatments were: heated 56° F., heated 51° F., heated (night) 42° F., insulated 32° F., semi-insulated 35° F., uninsulated 22° F., uninsulated 20° F. Lowest outside temperature was 21° F. below zero.

TABLE 5.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED INTAKE

| 1941-42 | No. of birds | Temperature | | | body wt. gain | Feed consumption | Feed for maintenance of body temp. | Egg production |
|---|---|---|---|---|---|---|---|---|
| | | Day | Night | Mean | | | | |
| | | °F. | °F. | °F. | gm/bird | gm./bird/day | gm./bird/day | gm./bird/day |
| Heated | 30 | 57.6 | 61.1 | 59.9 | 298.9 | 125.1 | 55.4 | 37.9 |
| Heated (night only) | 30 | 52.3 | 59.9 | 57.4 | 255.4 | 132.2 | 59.3 | 39.2 |
| Heated | 30 | 54.0 | 55.5 | 55.0 | 233.6 | 129.6 | 56.9 | 41.2 |
| Insulated | 55 | 42.9 | 44.3 | 43.8 | 183.2 | 142.1 | 66.4 | 37.3 |
| Semi-insulated* | 55 | 49.9 | 50.4 | 50.2 | 254.0 | 126.8 | 58.0 | 35.9 |
| Uninsulated | 55 | 42.6 | 45.2 | 44.3 | 264.2 | 149.8 | 69.6 | 39.8 |
| Uninsulated | 55 | 42.0 | 43.4 | 42.9 | 230.9 | 147.3 | 67.8 | 39.7 |

* Restricted ventilation.

Table 5 shows the results obtained. The pen heated at night only was 5.3° F. colder during the day than the warmest of the heated pens. Also, by restiction and control of ventilation the semi-insulated pen had a uniform day and night temperature approximately 7° F. higher than the insulated pen. This was accomplished without the excessive dampness characteristic of non-ventilated pens by judicious adjustment of ventilation during the warmest portion of the day. The greater window space of this pen again contributed to the higher temperature achieved and nullified the effect of complete insulation. Differences in egg production are not significant and production was quite good for the completely uninsulated pens. The greatest difference in feed required for maintenance was 14.2 grams per bird per day for a temperature difference of 15.6° F. On this basis the application of heat saved 4.7 lb. of feed per bird annually.

*Experiment 1942-43*

Since by far the most difficult matter to determine experimentally is the saving in feed accomplished through the application of heat to the pens, an experiment was planned for the sole purpose of measuring this factor. Since it was desirable to have as wide a range in temperature as possible, small, poorly insulated pens were used so that a very low temperature would be the result in the unheated pen. Electric heat was impossible under these conditions and a brooder stove was used in the heated pens. Colony houses 10′ × 12′ were used which had double boarded walls with building paper on studding forming a 4″-dead air space for back and side walls. The fronts were $\frac{1}{3}$ wood, $\frac{1}{3}$ glass and $\frac{1}{3}$ cotton and the ceiling was 4-inch thick straw loft between the 2″ × 4″ rafters of a shed roof. A small number of very late hatched birds was used so that the egg production was not of use as a direct measure of comparison. The feed required for this purpose could of course be estimated satisfactorily. The test covered a period from December 11, 1942 to March 29, 1943, a period of 109 days.

Lowest temperatures experienced inside the pens for the different treatments were: heated 28° F., heated 20° F., unheated 4° F. below zero. Lowest outside temperature was 36° F. below zero.

TABLE 6.—EFFECT OF HEAT ON REQUIREMENT OF FEED FOR MAINTENANCE OF BODY TEMPERATUTE.

| 1942-43 | No. of birds | Mean temperature | Feed consumption | Feed for maintenance of body temperature |
|---|---|---|---|---|
| | | ° F. | gm./bird/day | gm./bird/day |
| Heated | 27 | 52.3 | 89.69 | 45.6 |
| Heated | 48 | 47.8 | 96.00 | 48.2 |
| Unheated | 28 | 32.0 | 97.12 | 51.5 |

Table 6 shows the information obtained. It was found to be difficult to maintain the range of temperature which was intended between heated houses hence the results of 2 houses which had the same mean temperature were combined. Under unusually cold winter conditions, a temperature range of 20.3° F. was experienced with the mean temperature for the whole period being as low as 32° F. in the unheated pen. Great care was taken to have accurate figures on production, body weight and feed consumption. It was found that a saving of 5.9 gm. of feed per bird per day or 1.9 lb. of feed per bird per year was made. It was noted that the birds of the cold pen quite obviously attempted to adjust themselves to their environment. This consisted in a lowering of activity through standing in groups with the feathers ruffled, thus decreasing feed requirement to support activity, conserving heat by crowding together and increasing the insulating value of the feathers against heat loss from the body by entrapping more air amongst the feathers. It is suggested that these two factors begin to operate when temperatures go below a certain undetermined minimum thus making the environment more suitable to the bird. This factor makes the data for feed requirement for maintenance from this test not strictly comparable with that of those previously reported since these reactions were rarely noticed in previous experiments. The cost of fuel to bring about a temperature of 52.3° F. under these severe conditions was out of all proportion to practicability.

*Artificial Illumination 1939-40*[4]

A test involving a very large number of birds with 4 replications for each treatment was carried out to determine the effect of artificial light upon egg production. The lighted period was from October 5, 1939 to April 2, 1940, or 180 days. Morning lights were used and were turned on and off automatically to give sufficient artificial light to counteract the increasing and then decreasing hours of darkness before and after December 21, respectively, giving a reasonably constant light day of approximately 13 hours.

Table 7 shows the pertinent data, indicating a consistent effect of lights both in the case of replicate groups and the overall mean values.

[4] Project planned and carried out by Dr. S. S. Munro of this Division.

TABLE 7.—EFFECT OF LIGHT ON EGG PRODUCTION

| 1939-40 | No. of birds | Feed consumption | Egg production to Mar. 20 | Egg production to May 6 | Egg production to Aug. 7 | Egg production to Sept. 4 |
|---|---|---|---|---|---|---|
| | | gm./bird/day | No. | No. | No. | No. |
| Lighted | | | | | | |
| Pen 1 | 55 | 132.7 | 78.0 | 110.7 | 179.8 | 190.5 |
| 3 | 55 | 137.5 | 86.1 | 124.1 | 177.3 | 197.2 |
| 5 | 55 | 140.6 | 78.6 | 124.3 | 169.0 | 192.5 |
| 7 | 55 | 151.6 | 81.9 | 116.8 | 172.2 | 194.5 |
| Unlighted | | | | | | |
| Pen 2 | 55 | 126.7 | 74.4 | 118.2 | 171.0 | 195.7 |
| 4 | 55 | 128.1 | 63.3 | 110.2 | 167.8 | 193.3 |
| 6 | 55 | 126.4 | 57.8 | 99.0 | 160.8 | 178.0 |
| 8 | 55 | 120.2 | 57.2 | 103.0 | 163.3 | 181.8 |
| Lighted | 220 | 140.6 | 81.1 | 119.0 | 174.6 | 193.6 |
| Unlighted | 220 | 125.4 | 63.2 | 107.6 | 165.7 | 187.2 |
| Unlighted less than lighted % | | | 22.1 | 9.6 | 5.1 | 3.3 |

At March 20 which is the end of the calendar period most closely approximating the date of discontinuance of illumination, a significant difference in egg production had been brought about through the use of lights representing 17.9 eggs per bird or 22.1%. Between this point and May 6 a sharp decrease in rate of production for the lighted group reduced the difference to 11.4 eggs per bird and to August 7 and September 4 to 8.9 and 6.4 eggs per bird, respectively. This is in line with the findings of many other investigators.

## DISCUSSION

Most of the evidence presented in this paper relates to the application of artificial heat and the provision of insulation for the purpose of improving the physical comfort of laying birds. To be valid, an estimate of the effect of these factors should be made under conditions of severe cold which is provided in this instance by the climatic environment of the area in which this institution is situated (see Table 1). This, as may be judged by the meteorological data, is more severe than that of most areas in which poultry are kept on a commercial scale on this continent. Improving the physical comfort of the bird above a reasonable minimum is of little import unless the economy of its output is raised thereby. In this instance the installation of heating equipment, the fuel required for its operation as well as the cost of providing sufficient insulation to the building to make the operation of a heating unit reasonably economical or the raising of the temperature of the laying pen by insulation alone, must be considered. The saving of feed and litter are also matters for consideration.

The data presented herein show quite conclusively that the output of the bird is not improved by the application of heat or the provision of additional insulation. Experiments covering four years have consistently shown as high egg production in uninsulated, unheated pens as under conditions of heat or insulation. Mean temperatures in the pen during the winter months of 37.8° F., 39.1° F. and 42° F. gave as high egg production

as did those of 45.3° F., 50.6° F. or 59.9° F. Body weight gain also was not affected by temperatures within this range, variations which did occur being obviously unrelated to environmental temperature and caused by other factors.

Increase in environmental temperature must however, be reflected in a lowered heat loss from the body which means either a saving in actual feed consumption or the sparing of body supplies of fat which otherwise might be burned up in the process of maintaining body heat. An estimate of feed required to maintain body temperature was therefore made to determine the approximate saving in feed induced by higher environmental temperatures when production of eggs and gain in body weight were held constant. In 4 separate experiments in different years a saving of feed was accomplished during the winter months of 1.6 lb., 1.9 lb., 3.2 lb., and 4.7 lb. per bird under varying degrees of temperature difference. There is no substantial lack of agreement between these figures in so far as feed requirement and temperature range is concerned excepting in the case of the 1941-42 data where the requirement of feed for maintenance of body heat is very large in relation to the severity of the lowering of temperature. Since allotment of the feed consumed to that required for weight gain and egg production and its deduction from the total feed was carried out in an identical way to that of the other experiments, the total feed consumption, if anything, is at fault. Very careful checking indicates these figures to have been correct and it is difficult therefore to explain the larger feed requirement per degree of temperature decrease in this instance. Greater reliance can be placed, however, upon the 1942-43 figures, hence it is assumed that the figure for that year is probably a better estimate of the true situation. To be conservative the mean value for the four years of 2.85 lb. per bird for maintenance of body temperature is considered to be the best estimate of the saving possible under the temperature ranges quoted above, and a very small saving indeed was involved in the application of heat or insulation. Admittedly, a considerable saving in litter and labour of changing litter in the heated pens is involved. This saving is at least counteracted by the costs of installation of heating equipment and fuel consumed. Application of the results of these findings must be conditioned by the important fact that a temperature range at the level of the birds of from 37.8° F. to 59.9° F. was the case in these tests. Much lower temperatures might have a different effect but the observation that no greater saving of feed was accomplished at a mean temperature of 32° F. and of the behaviour of the birds in adapting themselves to this temperature by ruffling of the feathers to increase their insulating power and in other ways would suggest that the above findings would hold for a much lower temperature range. In further support of this contention, at the Experimental Station, Kapuskasing, Ontario, under very severe weather conditions in a preliminary test using 2 pens of 50 birds, heated and 2 pens unheated, egg production was 72.3 eggs per bird for the heated groups and 69.8 eggs for the unheated from November 1 to April 1, a negligible difference. The mean outside temperatures for each of the 6 months were 22.2° F., 7.2° F., −1.5° F., 2.5° F., 13.6° F. and 31.1° F. Our records show a series of 30 consecutive days at Kapuskasing only 2 of which were above zero and going as low as 43° F. below zero. Inside pen tempera-

tures in the test under consideration averaged 14° F. lower than was usually the case in Ottawa experiments. On September 4 the production of these groups was 185.2 and 190.6 eggs per bird respectively. Under the meteorological conditions in the Ottawa area a house constructed similarly to the uninsulated pens of these tests may be expected to give as high egg production as heated or well insulated pens at only a very slightly greater increase in feed consumption. This construction is as follows: boarding of rear and side walls inside and outside of the studs with paper between boards and the studding making a 4-inch air space, with $\frac{1}{3}$ wood, $\frac{1}{3}$ cotton and $\frac{1}{3}$ glass front construction, and straw loft ceiling.

Attention is drawn to the fact that by judicious adjustment of the ventilation, that is, no ventilation at night and increased ventilation during the warmest part of the day to change air and remove moisture, an increase in mean temperature of 7° F. was accomplished which gave the pen thus treated the equivalent of heat at 50° F.

The effect of artificial illumination is also briefly recorded showing a definitely increased egg production for the lighted pens during the winter months but an almost identical production at the end of the laying year.

## SUMMARY

Four separate experiments carried out in different years between 1932-33 and 1941-42 contrasting artificial heat, two different degrees of insulation, and uninsulated pens are reported as well as a test to determine the saving of feed accomplished by artificial heat under an extreme range of temperature conditions. A 1-year test of the effect of artificial illumination is also recorded.

From the consideration of the data obtained the following conclusions seem justified:—

1. Increasing the environmental temperature of laying pullets by the use of artificial heat and insulation over a range of 37.8° F. to 59.9° F. had no effect upon egg production. Even when temperature was thermostatically controlled to a range of ± 4° F. in the heated pen no improvement in production was obtained.

2. The maximum saving in feed accomplished through the decreased requirement of feed for the maintenance of body temperature under heated conditions was 4.7 lb. per bird annually with a mean saving of 2.85 lb. The mean inside pen temperature range in these tests was from 32° F. to 59.9° F.

3. Restriction of ventilation to a minimum, all ventilators being completely closed with a resulting temperature of 45.6° F. and very high humidity and carbon dioxide content of the air had no detrimental effect upon egg production.

4. The reduction of window area in an attempt to supply more insulation is not justified under conditions similar to those in this test since the effect of reducing window space by one-half, because of exclusion of sunshine, nullified the effect of complete insulation and gave equal or higher mean temperatures in the uninsulated pens.

5. The use of artificial illumination significantly increased egg production during the winter months but resulted in approximately the same annual production.

It is concluded that laying pullets will produce well under a very wide range of temperatures and conditions of humidity, and that neither artificial heat nor insulation, as herein defined, would be justified under temperature conditions similar to or less severe than those experienced in this area. These conclusions have been arrived at under conditions of severe cold and therefore constitute a severe test of the housing conditions investigated.

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# THE DIGESTIBILITY OF TYPICAL EASTERN CANADIAN FEEDS BY MARKET BACON HOGS, III.[1]

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As a sequel to reports on previous study in this laboratory on the digestibility of feeds by swine this paper presents further work on the investigation started in 1941[4].

Concurrently with the determination of digestibility coefficients of the proximate principles of the standard feeding stuffs analysis, studies were continued on the proposed system of feeding stuffs analysis as reported by Crampton and Whiting (1).

## EXPERIMENTAL

The animals chosen for the test were 4 closely related Yorkshire barrows. They commenced trial periods at weights of 50, 100, 150, and 200 pounds.

Table 1 shows the allotment of the pigs by weights, feeds, and trial periods. The digestion crates have been described previously (2).

TABLE 1.—PLAN OF DIGESTION TRIALS, SHOWING NUMBERS AND ALLOTMENT OF ANIMALS TO FEEDS IN EACH PERIOD

| Rations | Period 1 50 lb. pig | Period 2 100 lb. pig | Period 3 150 lb. pig | Period 4 200 lb. pig |
|---|---|---|---|---|
| No. 2 Yellow Corn | 78 | 79 | 47 | 61 |
| No. 2 N. Wheat | 79 | 47 | 61 | 78 |
| Degermed Shorts | 47 | 61 | 78 | 79 |
| Standard Shorts | 61 | 78 | 79 | 47 |

The swine feeds tested during 1943 were yellow corn, wheat, and two kinds of wheat shorts; one sample containing the germ while the other had had most of the germ removed in the process of preparation of "Canada Approved" flour. Though not now differentiated from standard shorts it seemed probable that degerming might sufficiently alter the feeding value of the latter product that some distinction would be necessary between the two types of shorts as livestock feeds.

In addition to the digestion period schedule, as planned, an extra test was introduced between periods 2 and 3 in which all animals were fed degermed shorts.

[1] Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 191.

[2] Professor of Animal Nutrition.

[3] Graduate Assistant, Department of Nutrition.

[4] These studies were made possible through the financial assistance of the Quebec Department of Agriculture.

It was necessary to obtain a new sample of corn for periods 3 and 4 because of a rancid condition that developed in the original mixed ration.

A protein-mineral supplement consisting of 25 parts meat meal, 40 parts linseed oil meal, 15 parts fish meal, 10 parts bone char, 5 parts ground limestone and 5 parts salt was fed with all the basal feeds in all tests at the rate of 15% of the total ration (see Table 2 for analysis). In addition, cod liver oil was fed daily during the first two periods.

Feeding was done three times daily to pigs under 150 lbs., i.e., during periods 1 and 2, and twice daily to heavier pigs. Between trials the animals were removed to the farm piggery where they were maintained on a ration of equal parts of wheat and barley, supplemented as in the experimental diets.

A preliminary period of 5 days preceded each 10-day collection period in order to clear the digestive tract of previous dietary residues and adjust the feed consumption of the animals to full and constant feed intakes before the excretia collections commenced.

Faeces collections were made once daily at approximately 9.00 o'clock in the morning. Representative aliquots were taken for chemical analysis.

Urine was collected twice daily at 9.00 a.m. and 5.00 p.m. One one-hundredth (1/100) aliquots were preserved under toluene in $H_2SO_4$ and acetic acid during each trial. Nitrogen determinations were made by the Kjeldahl method.

The percentage composition of the basal feeds and supplement are presented in Table 2.

TABLE 2.—CHEMICAL COMPOSITION OF BASAL FEEDS AND SUPPLEMENT

| Feed fraction | No. 2 Yellow corn | | No. 2 Canadian northern wheat | Degermed shorts | | Standard shorts | Supplement mixture |
|---|---|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | | Sample 1 | Sample 2 | | |
| Water | 9.0 | 9.0 | 11.0 | 10.0 | 9.0 | 10.0 | 8.5 |
| Protein (N × 6.25) | 8.9 | 9.0 | 16.4 | 20.0 | 19.2 | 17.8 | 34.8 |
| Soluble protein* | 6.2 | 7.0 | 14.6 | 16.7 | 17.7 | 15.3 | 30.3 |
| Insoluble protein* | 2.7 | 2.0 | 1.8 | 3.3 | 1.5 | 2.5 | 4.5 |
| Ether extract | 1.9 | 2.8 | 1.5 | 4.4 | 4.2 | 3.9 | 5.0 |
| Total ash | 1.6 | 1.4 | 1.4 | 4.3 | 5.2 | 4.1 | 25.5 |
| Carbohydrates | | | | | | | |
| Crude fibre | 2.7 | 2.1 | 2.4 | 8.6 | 9.8 | 10.4 | 6.6 |
| Nitrogen-free extract | 75.9 | 75.7 | 67.3 | 52.7 | 52.6 | 53.8 | 19.6 |
| Carbohydrates* | 2.1 | 1.9 | 2.0 | 6.9 | 8.2 | 7.0 | 4.6 |
| Soluble carbohydrates | 75.8 | 75.0 | 66.2 | 50.3 | 47.2 | 50.9 | 17.8 |
| Lignin (by difference) | 0.7 | 0.9 | 1.5 | 4.1 | 7.0 | 6.3 | 3.8 |
| Lignin** + Insol. protein | 3.9 | 3.3 | 3.9 | 8.4 | 9.6 | 9.9 | 9.3 |

* From scheme of feeding stuffs analysis by Crampton and Whiting. (See Appendix).
** Lignin determined directly and added to Insoluble Protein.

## DIGESTIBILITY OF FEED CONSTITUENTS

The "by-difference" method of calculating the digestibility coefficients was employed for the basal feeds studied, using the formula:

$$Cx = \frac{mR - [F - R(n)\,(1.00 - Cy)] \times 100}{mR}$$

where $m$ = percentage of nutrient contributed by basal diet.
$n$ = percentage of nutrient contributed by supplement mixture.
$R$ = weight of total ration or ration constituent consumed.
$F$ = weight of total faeces or faeces constituent produced.
$Cy$ = the digestibility coefficient of the constituent in the supplement mixture.

Digestibility coefficients obtained on the four basal feeds are presented in Table 3 along with some comparable coefficients obtained with ruminants by other investigators. No significant differences were noted between the two corn samples so the average coefficients are reported in the table. All calculations were made on the regular 10-day time collections.

TABLE 3.—COEFFICIENTS OF DIGESTIBILITY, TOTAL DIGESTIBLE NUTRIENTS AND DIGESTIBLE CRUDE PROTEIN OF FEEDS LISTED

| — | No. 2 Yellow corn | No. 2 Canadian northern wheat | Degermed shorts | Standard shorts | Supplement mixture | Degermed shorts (Sample 2)* |
|---|---|---|---|---|---|---|
| Dry Matter | 90 | 88 | 67 | 68 | 43 | 63 |
| Organic Matter | 88 | 85 | 65 | 67 | 50 | 63 |
| Protein (N × 6.25) | 88 (76) | 89 (86) | 79 | 81 (85) | 71 | 81 |
| Soluble Protein | 89 | 92 | 86 | 88 | 82 | 87 |
| Insoluble Protein | 87 | 66 | 46 | 38 | 0 | 74 |
| Ether Extract | 38 (91) | 32 (83) | 50 | 47 (85) | 100 | 41 |
| Carbohydrates† | | | | | | |
| Crude Fibre | 37 (57) | −1 (90) | 17 | 26 (60) | 37 | 19 |
| Nitrogen-Free-Extract | 94 (94) | 94 (95) | 76 | 77 (85) | 0 | 73 |
| Carbohydrates‡ | | | | | | |
| Cellulose | 24 | −6 | 15 | 15 | 32 | 19 |
| Soluble Carbohydrates | 97 | 95 | 78 | 79 | 8 | 75 |
| Lignin (by difference) | −94 | 7 | 19 | 47 | 15 | 44 |
| Lignin + Insol. Protein | 42 | 35 | 31 | 46 | | 35 |
| Digestible Crude Protein | 8 (7) | 15 (11) | 16 | 15 (15) | 25 | 16 |
| Total Digestible Nutrients† | 83 (81) | 79 (84) | 62 | 63 (76) | 32 | 59 |
| Total Digestible Nutrients‡ | 83 | 78 | 62 | 60 | 33 | 56 |

* Shorts fed during separate trial between Periods 2 and 3.
† By Proximate principles scheme of feedstuffs analysis.
‡ Method proposed by Crampton and Whiting. (See Appendix.)
Figures in parentheses are digestion coefficients obtained from tests with ruminants on similar feeds.

In Table 3 are included determinations by the Crampton and Whiting procedure for feeding stuffs analysis. Carbohydrates were divided into cellulose, soluble carbohydrates and a lignin-by-difference fraction for comparison with the crude fibre and nitrogen-free-extract division. Coefficients are also presented for a fraction representing the lignin (direct) plus the "insoluble protein" (i.e. insoluble after refluxing for 3 hours in 1% HCl. See appendix.)

## DISCUSSION

The digestibility of dry matter was significantly higher in the case of wheat and corn than in shorts. It is probable that the laxative properties of the shorts were an influential factor in depressing the apparent digestibility of their dry matter.

The ether extract, a fraction which showed rather variable results, was slightly better digested in shorts than in corn or wheat.

Crude fibre digestibility coefficients in all cases were very low. The coefficients were higher in standard than degermed shorts. There is no theoretical reason for this, which leads to the conclusion that crude fibre isolated in the one case differs from that obtained in the other as later mentioned. In contradistinction to this is the case of cellulose where the digestibility of this fraction is the same for each type of shorts. The erratic values of whole wheat are explainable on the basis of low crude fibre in the basal feed itself and the errors inherent in the "difference" method of calculation. The crude fibre of corn was better digested than that of wheat as shown by both wheat and shorts.

The digestibility of nitrogen-free-extract in corn and wheat was about equal, both the coefficients in the entire grains being considerably higher than in the shorts samples.

Coefficients for soluble carbohydrates parallel those obtained for nitrogen-free-extract as could be expected because of the similarity between these fractions in concentrate feeds. Soluble carbohydrates probably tend to be better digested because the proposed scheme of analysis relegates some of the formerly indigestible nitrogen-free-extract fraction to the less digestible fraction called lignin-by-difference. Consequently the remaining nutrients of the nitrogen-free-extract, the soluble carbohydrates, constitute the more highly digestible and probably more useful fraction.

"Lignin" gave very low and irregular results with corn and wheat where the percentage lignin in the basal feeds was small and hence subject to greater error in determination. The coefficients for shorts were however consistently higher than in the case of the whole grains.

Another fraction, lignin plus "insoluble protein", (see appendix) which was not included in either of the schemes of feeding stuffs analysis, showed digestibility coefficients of a more consistent nature than the lignin-by-difference fraction. No negative values for this fraction were obtained for any of the feeds studied.

The crude protein in corn and wheat appears to be better digested by swine than the protein in shorts. This is most likely due to the effects of the lower fibre content of the grains.

Data relative to the usefulness of protein in these feeds are presented in Table 4.

TABLE 4.—NITROGEN DIGESTED, RETAINED AND EXCRETED BY PIGS

| Ration | Percentage of total nitrogen digested | Percentage of digested nitrogen retained in the body | Percentage of total intake excreted in urine |
|---|---|---|---|
| | % | % | % |
| No. 2 Yellow corn + supplement | 81 | 33 | 56 |
| No. 2 N. wheat + supplement | 84 | 31 | 60 |
| Degermed shorts (1) + supplement | 78 | 37 | 53 |
| Degermed shorts (2) + supplement | 78 | 35 | 51 |
| Standard shorts + supplement | 79 | 39 | 51 |

There may be a tendency for retention of a greater proportion of the digested nitrogen in shorts than is the case with corn or wheat. These differences between feeds in nitrogen utilization, however, are of little significance partly because the supplement was the main source of protein in all rations and partly because the availability of the dietary protein was undoubtedly affected by the relative laxative properties of the diets.

The division of crude protein into soluble and insoluble protein gave greater differences in digestibility between the two fractions where the total protein in the feedingstuff was higher. In corn where nearly one-third of the total protein was insoluble the digestibility of the insoluble was approximately the same as the soluble portion. In wheat (and the wheat products), in which the total protein was approximately double that of corn, the insoluble fraction represented one-seventh to one-ninth of the total protein and had correspondingly lower digestibility coefficients. Although the variability between animals (or periods) was considerably greater than that shown for dry matter digestibility coefficients it is reasonable to suppose that the soluble protein represents a fraction least affected by physical or chemical combination in the feed and hence more readily available to the animal organism. Conversely it may be expected that the insoluble fraction would give variable results depending on laxation, feed preparation, and amount of total protein.

In connection with Table 3 it is interesting to notice that the separation of carbohydrates into cellulose, soluble carbohydrates, and lignin, by the method of Crampton and Whiting has caused no significant change in the calculated total digestible nutrients. Close agreement exists in all the total digestible nutrient figures obtained by either method in spite of the highly variable lignin fraction in the new scheme.

## CHEMICAL DESCRIPTION AS AN INDEX OF FEEDING VALUE

Although no appreciable differences in the digestibility or nutritive value of the standard and degermed shorts appears evident from the chemical composition and digestibility data so far presented it seems worthwhile to comment on the growth of the animals while on test. Table 5 shows

the average daily gains made by the animals on each of the four rations over the four trial periods. Thus each gain indicated represents all 4 pigs.

TABLE 5.—AVERAGE DAILY GAINS OF ANIMALS WHILE ON TEST

| Ration | Average daily gain over four 15-day periods* | Total dig. nutrients** | |
|---|---|---|---|
| | | Percentage in ration | Lb. eaten daily |
| | lb. | | |
| No. 2 Yellow corn + supplement | 1.18 | 83.3 | 3.31 |
| No. 2 N. wheat + supplement | 1.22 | 78.8 | 3.07 |
| Degermed shorts + supplement | 0.64 | 62.2 | 2.48 |
| Standard shorts + supplement | 1.14 | 62.5 | 2.41 |

* Includes the preliminary period of 5 days.
** On same moisture basis as in Table 2.

Since the response of the animals must remain the critical test of the true value of any feed this table of gains appears to indicate a deficiency in degermed shorts that was not made apparent by the chemical analysis. The fact that standard shorts gave nearly twice the daily gains of the degermed product is an important distinction between the two shorts samples. These data seem to bear out statements made previously that there is a tendency for wheat germ to stimulate, or facilitate, synthesis and deposition of body fat from dietary carbohydrate (3).

The failure of the crude fibre fraction to represent a biological or a chemical entity is clearly indicated in Table 2. The division of the crude fibre, in the case of standard shorts, into cellulose, lignin, and perhaps some carbohydrates, was different than in the case of the degermed shorts. The crude fibre digestibility coefficients were different; 16.9% for degermed shorts and 26.1% for standard shorts, whereas the cellulose coefficients were the same (14.5% and 14.7% respectively) showing that the crude fibre contained some highly variable constituents. The lignin digestibility coefficient for standard shorts was correspondingly higher than for degermed shorts thus compensating for the proportionately larger difference between crude fibre and cellulose coefficients.

The fraction called total digestible nutrients, which is determined from chemical composition modified by the digestibility coefficients gives undoubtedly valuable information in relation to any feedingstuff, but it gave a false estimation of the relative feeding values of the rations studied here. Standard shorts allowed gains almost equal to those of corn yet there was a difference of 20 percentage units in the total digestible nutrients values. Similarly the total digestible nutrient values of the two types of shorts offer no clue to the difference in animal response when it is known that the dry matter consumption was approximately equal for all feeds in each period.

These observations and criticisms of present feeding stuffs analyses seem to demand more informative methods of feed evaluation.

## CONCLUSIONS

1. The digestibility of the chief energy yielding constituents of wheat and corn, namely protein, ether extract, and soluble carbohydrates are remarkably similar between the two feeds, as shown by swine digestibility trials.

2. Although the content and digestibility coefficients of the organic fractions of standard and of degermed shorts were quite similar, the growth rate of the animals while on test indicated superiority of the "standard" shorts.

3. Feed fractions constituting a small proportion of the ration are subject to proportionately greater error in digestibility trials than are the major fractions as indicated by negative digestibility coefficients for lignin-by-difference in corn and for crude fibre and cellulose in wheat.

4. The digestibility coefficients for the various feed fractions are sufficiently different from those determined with ruminants to warrant separate investigations with swine.

## REFERENCES

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2. CRAMPTON, E. W. and F. WHITING. The digestibility of typical Eastern Canadian feeds by market bacon hogs. Sci. Agric. 23: 9. 1943.

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## APPENDIX

### DESCRIPTION OF FEEDS

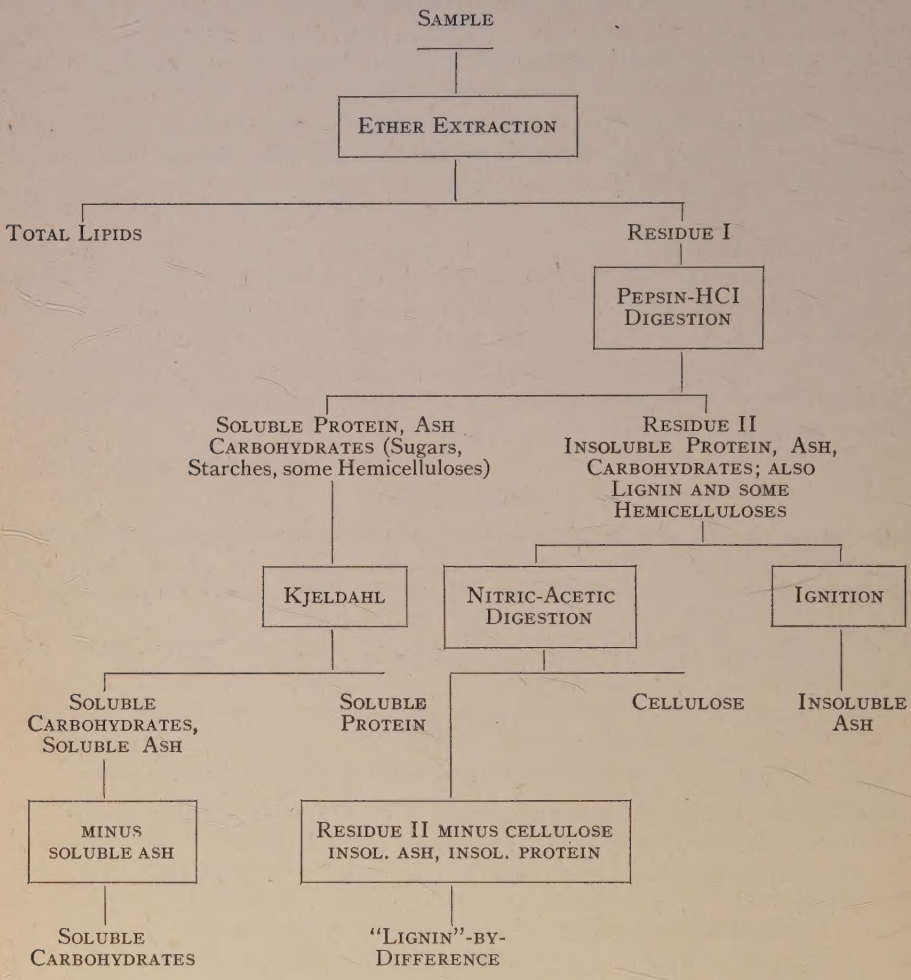
No. 2 Yellow Corn. The second grade of Eastern Canadian grown yellow corn. It was free of weed seeds and damaged kernels. The required quantity was ground to medium fineness and mixed with protein mineral supplement prior to first and third periods. A second lot was mixed for periods 3 and 4 owing to the rancidity of the first lot.

No. 2 Northern Wheat. The third grade of Canadian Hard Red Spring wheat. Practically free of weed seeds. Ground and mixed prior to the commencement of the test.

Standard Shorts. Consists of fine particles of bran, germ, and a small percentage of low grade flour as separated in the ordinary process of flour milling.

Degermed Shorts. Two separate samples were obtained; one used throughout the test and the other used in the supplementary period. This product was similar to the standard shorts used except that it was a by-product of the Canada Approved flour hence was lower in wheat germ content.

Figure 1—Diagrammatic Outline of Crampton and Whiting Scheme of Proximate Principle Feed Analysis




Soluble Ash = Total Ash (from separate sample) minus Ash of Residue II.
Insoluble Protein = Total Protein (from separate sample) minus Soluble Protein.